AN ATLAS OF STELLAR SPECTRA

WITH AN OUTLINE OF SPECTRAL CLASSIFICATION

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W. W. MORGAN PHILIP C. KEENAN EDITH KELLMAN

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Preface to the ULO Version

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While every effort has been made to ensure that this version of the Atlas is a faithful copy of the original, mistakes may have occurred. Please submit corrections to `mmd@ulo.ucl.ac.uk`.

This version includes a table of contents, a list of tables and a star name index not included in the original version of the Atlas.

High resolution scans of the catalogue plates are available on the World Wide Web. The home page for these is:

`www.ulo.ucl.ac.uk/catalogues/mkkatlas/`

We thank Miss Deborah Scammell for performing the plate scanning.

University of London Observatory,
Mill Hill Park, London.
July 2004.

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I Introduction

The *Atlas of Stellar Spectra* and the accompanying outline have been prepared from the viewpoint of the practical stellar astronomer. Problems connected with the astrophysical interpretation of the spectral sequence are not touched on; as a consequence, emphasis is placed on “ordinary” stars. These are the stars most important statistically and the only ones suitable for large–scale investigations of galactic structure. The plan of the *Atlas* can be stated as follows:

a. To set up a classification system as precise as possible which can be extended to stars of the eighth to twelfth magnitude with good systematic accuracy. The system should be as closely correlated with color temperature (or color equivalent) as is possible. The criteria used for classification should be those which change most smoothly with color equivalent.

b. Such a system as described under (a) requires a classification according to stellar luminosity, that is, the system should be two–dimensional. We thus introduce a vertical spectral type, or luminosity class; then, for a normal star, the spectrum is uniquely located when a spectral type and a luminosity class are determined. The actual process of classification is carried out in the following manner: (1) an approximate spectral type is determined; (2) the luminosity class is determined; (3) by comparison with stars of similar luminosity an accurate spectral type is found.

As it may not be immediately apparent why an increase in accuracy in spectral classification is desirable, a short digression on some problems of stellar astronomy will be made.

The problem of stellar distribution in the most general sense does not require any spectroscopic data. Stars of all types and temperatures may be considered together, and some general features of the distribution of stars in the neighborhood of the sun can be found. For this purpose a certain frequency distribution of stellar luminosities must be assumed. This luminosity function has a large dispersion and must be varied with galactic latitude. In addition, there are certain regional fluctuations in the frequency of stars of higher luminosity of classes B, A, and M.

As a result of these considerations (and because of difficulties with interstellar absorption) the general method has very definite limitations; the large dispersion of the luminosity function means we must have a large sample, and this in itself precludes detailed analyses of limited regions. In addition, there is evidence of clustering tendencies for stars of certain spectral type – a cluster or star cloud might be well marked for stars of type A, for example, and be not at all apparent from a general analysis of star counts.

There is, then, for certain kinds of problems a great advantage in the use of spectral types of the accuracy of the *Henry Draper Catalogue*. Consider, for example, the stars of classes B8–A0 as a group. The dispersion in luminosity is far less than in the case of the general luminosity function, and the space distribution of stars of this group can be determined with a correspondingly higher accuracy. In addition, we are able to correct for systematic errors due to interstellar absorption from observations of the color excesses of these stars. We have thus gained in two particulars: we have limited at one time the dispersion in luminosity and in normal color.

The further refinement of a two–dimensional classification makes possible an even greater reduction in the dispersion in absolute magnitude for groups of stars. The mean distance of a group of stars of the same spectral type and luminosity class can be determined with great precision, even when the group consists of a relatively small number of stars. Even for individual stars distances of good accuracy can be derived. A corresponding gain is made in problems concerned with intrinsic colors and interstellar absorption.

In the fifty–five prints which make up the accompanying atlas an attempt has been made to show most of the common kinds of stellar spectra observed in stars brighter than the eighth magnitude. The dispersion selected is intermediate between that used for very faint stars, where only a few spectral features are visible, and the larger–scale slit spectra which show a multitude of details. A sufficient number of lines and bands are visible to allow an accurate classification to be made, both by temperature and by luminosity equivalent, while the relatively low dispersion makes it possible to observe bright and faint stars in a uniform manner and avoids the possibility of appreciable systematic differences in their classification.

A small one–prism spectrograph attached to the 40–inch refractor was used to obtain the plates. The reduction of collimator to camera is about 7; this makes it possible to use a fairly wide slit and still have good definition in the resulting spectra. The spectrograph was designed by Dr. Van Biesbroeck and constructed in the observatory shop by Mr. Ridell. The camera lens was constructed by J. W. Pecker, according to the design of Dr. G. W. Moffitt. The usable spectral region on ordinary blue–sensitive plates is from the neighborhood of K to $H\beta$ ($\lambda\lambda$ 3920–4900).

The dispersion used (125 Å per mm at $H\gamma$) is near the lower limit for the determination of spectral types and luminosities of high accuracy. The stars of types F5-M can be classified with fair accuracy on slit spectra of lower dispersion, but there is probably a definite decrease in precision if the dispersion is reduced much below 150 Å per mm.

The lowest dispersion capable of giving high accuracy for objective–prism spectra is greater; the limit is probably near 100 Å per mm. The minimum dispersion with which an entirely successful two–dimensional classification on objective–prism plates can be made is probably near 140 Å per mm. This value was arrived at from a study of several plates of exquisite quality taken by Dr. J. Gallo, director of the Astronomical Observatory at Tacubaya, Mexico; for plates of ordinary good quality the limit is probably considerably higher.

The *Atlas* and the system it defines are to be taken as a sort of adaptation of work published at many observatories over the last fifty years. No claim is made for originality; the system and the criteria are those which have evolved from a great number of investigations. Specific references to individual investigations are, as a rule, not given.

By far the most important are those of the investigators at Harvard and Mount Wilson. The idea of a temperature classification is based on the work of Miss Maury and Miss Cannon at Harvard and of Sir Norman Lockyer. We owe to Adams the first complete investigation of luminosity effects in stellar spectra. If we add to this the work of Lindblad on cyanogen and the wings of the Balmer lines in early–type stars and the investigations of the late E. G. Williams, we have the great majority of the results on which the new classification is based. References to individual papers are given in the *Handbuch der Astrophysik*.

The present system depends, then, to a considerable extent on the work of these investigators, combined with data which were not available until recently. These data are of two kinds: accurate color equivalents for many of the brighter stars and accurate absolute magnitudes for a number of the same stars. These results have been used to define the system of classification more precisely, both in the temperature equivalents and in the luminosity class. The most important of the determinations of color equivalents for this purpose are the photoelectric colors of Bottlinger and of Stebbins and his collaborators and the spectrophotometric results of the Greenwich Observatory and those of Hall.

The absolute magnitudes used depend on a variety of investigations. There are the classical catalogue of trigonometric parallaxes of Schlesinger; the catalogue of dynamical parallaxes of Russell and Miss Moore; various cluster parallaxes, principally due to Trumpler; and, in the case of the stars of earlier class, parallaxes from interstellar line intensities and from the effects of galactic rotation.

Throughout the discussion emphasis will be laid on the "normal" stars. A number of peculiar objects are noted; but the main aim of the investigation has been to make the classification of the more frequent, normal stars as precise as possible for the use of the general stellar astronomer. This investigation is not concerned with the astrophysical aspects of stellar spectra or with the spectra of the dwarfs of low luminosity. Relatively few of the latter are met with among stars brighter than the eighth magnitude, and their classification can be considered as a separate problem.

There appears to be, in a sense, a sort of indefiniteness connected with the determination of spectral type and luminosity from a simple inspection of a spectrogram. Nothing is measured; no quantitative value is put on any spectral feature. This indefiniteness is, however, only apparent. The observer makes his classification from a variety of considerations–the relative intensity of certain pairs of lines, the extension of the wings of the hydrogen lines, the intensity of a band–even a characteristic irregularity of a number of blended features in a certain spectral region. To make a quantitative measure of these diverse criteria is a difficult and unnecessary undertaking. In essence the process of classification is in recognizing similarities in the spectrogram being classified to certain standard spectra.

It is not necessary to make cephalic measures to identify a human face with certainty or to establish the race to which it belongs; a careful inspection integrates all features in a manner difficult to analyze by measures. The observer himself is not always conscious of all the bases for his conclusion. The operation of spectral classification is similar. The observer must use good judgment as to the definiteness with which the identification can be made from the features available; but good judgment is necessary in any case, whether the decision is made from the general appearance or from more objective measures.

The problem of a classification according to luminosity is a difficult one. In the first place, lines or blends which may be useful at one spectral type may be quite insensitive at another. In fact, some lines which show a positive absolute–magnitude effect for some spectral classes may show a negative one for others. This is true for certain lines of *H*, *Sr* II , and *Ba* II .

Besides the variation with spectral type, there is also a very marked change in appearance with the dispersion of the spectrograms used. Some of the most useful indicators of absolute magnitude are lines and blends which can be used only with low dispersion. The hydrogen lines, for example, show marked variations with absolute magnitude in spectra as early as

B2 and B3 on plates of low dispersion; with higher dispersion the wings which contribute to the absolute–magnitude effect are not apparent to the eye, and the lines look about the same in giants and dwarfs. In stars of classes G2–K2 the intensity of the *CN* bands in the neighborhood of λ 4200 is one of the most important indicators of absolute magnitude. The band absorption has a different appearance on spectrograms of high and low dispersion, and it is doubtful whether high–dispersion plates show the luminosity effects of *CN* as well as those of low dispersion.

On the other hand, a considerable number of sensitive line ratios are available on high–dispersion spectra which cannot be used with lower dispersion. One of the most sensitive lines to absolute–magnitude differences for the F8–M stars is *Ba* II 4554; this line is too weak to be observed on low dispersion spectra. A number of the other ratios found by Adams to be sensitive indicators of absolute magnitude are also too weak to be used with low dispersion.

These considerations show that it is impossible to give definite numerical values for line ratios to define luminosity classes. It is not possible even to adopt certain criteria as standard, since different criteria may have to be used with different dispersion. In the *Atlas* some of the most useful features for luminosity classification have been indicated, but it should be emphasized that each dispersion has its own problems, and the investigator must find the features which suit his own dispersion best.

The luminosity classes are designated by Roman numerals; stars of class I are the super-giants, while those of class V are, in general, the main sequence. In the case of the B stars the main sequence is defined by stars of classes IV and V. For the stars of types F–K, class IV represents the subgiants and class III the normal giants. Stars of class II are intermediate in luminosity between the super–giants and ordinary giants.

II The 05–F2 Stars

The varying degree of diffuseness in line character for stars earlier than class F5 presents an additional difficulty in their classification. On plates having a dispersion of around 30 Å per mm the lines have such a varied appearance that it is almost impossible to classify the spectra on a uniform system. If the dispersion is reduced to lessen this effect, the lines in general become fainter.

The best compromise seems to be a dispersion of around 125 Å per mm and greatly broadened spectra on high–contrast plates. Spectra of this dispersion can be classified with high accuracy for stars of classes O–B5 inclusive, if a fine–grain emulsion is used. The varying widths of the spectral lines are not very noticeable, except for a very few stars with exceedingly broad lines.

Spectra of classes B9–A2 are most difficult of all to classify accurately. All lines with the exception of the Balmer series are weak, and the broad–line stars show few spectral features that can be used. By the time class A3 is reached, numerous metallic lines make their appearance, and classification becomes progressively easier on passing toward lower temperature.

Dispersions higher than 125 Å per mm can be used to classify the early–type stars, if a certain rough ratio is preserved between the dispersion and the spectrum width. For the highest accuracy the width of the spectrum should be about one–third the distance between $H\gamma$ and $H\delta$. With plates of higher dispersion a corresponding reduction in the magnifying power of the viewing eyepiece should be made. For spectra later than F0 a width of about one–sixth the distance between $H\gamma$ and $H\delta$ is sufficient, unless the dispersion is less than 125 Å per mm. Wide spectra for the late–type stars allow the use of the G band and other important blended features. The advantage of using broad spectra is somewhat similar to that of extra–focal images in stellar photometry.

1 The O Stars

Star	Sp_{MKK}	Sp_{HHP}	α	δ	m	HD	Notes
ζ Pup	O5	...	08:00	−39°43′	2.3	Od	
9 Sgr	O5	O5	17:57	−24 22	5.9	Oe5	1
λ Cep	O6	O6	22:08	+58 55	5.2	Od	
HD 5005	O6	...	00:47	+56 05	7.7	B2	1
θ^1 Ori C	O6	O7	05:30	−05 27	5.4	Oe5	2
HD 165052	O7	O6	17:50	−24 24	6.8	Oe5	1
S Mon	O7	O7	06:35	+09 59	4.7	Oe5	
ξ Per	O7	...	03:52	+35 30	4.1	Oe5	
λ Ori A	O8	O8	05:29	+09 52	3.7	Oe5	
ι Ori	O9 V	O9	05:30	−05 59	2.9	Oe5	3
10 Lac	O9 V	O9	22:34	+38 32	4.9	Oe5	3
HD 188209	O9 I	...	19:49	+46 47	5.5	B0	4
HD 218915	O9 I	...	23:06	+52 31	7.1	B0	4

[1] No emission lines visible on low–dispersion spectrograms. *He* II 4686 is much stronger than λ 4650.

[2] The H lines are abnormally broad in comparison to other absorption lines.

[3] Main–sequence star. Luminosity differences at O9 are shown by the following ratios: λ 4068:λ 4089, λ 4387:λ 4541, and λ 4650:λ 4686.

[4] O–type supergiants.

Table 1: Classification of the O Stars

No luminosity classification has been attempted for stars earlier than O9. The spectral type has been determined from the ratio *He* I 4471: *He* II 4541. The types determined from this ratio appear to be consistent with the appearance of other spectral features in a sequence of effective excitation. The types obtained in this manner are in very close agreement with those determined by H. H. Plaskett.[1]

If the spectral types of the O stars are determined from the single ratio of the absorption lines *He* I 4471: *He* II 4541, results accurate to a tenth of a class between O5 and O9 can be obtained on plates of the dispersion used (125 Å per mm at $H\gamma$). This single ratio appears to be the most useful criterion of spectral type for O5–O9 stars on spectra similar to those used. The classification of the Wolf–Rayet stars as a group will not be discussed;

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[1] *Pub. Dom. Ap. Obs.*,**I**,365,1922.

the number of stars in this class is very small, and individual description of each spectrum seems to be necessary.

The standard O stars are listed in Table 1. Notes concerning spectral features for some of the stars are given; in the case of those of class O9, luminosity differences are also noted.

2 O9.5

At class O9.5 the line at λ 4200 is intermediate in intensity between O9 and B0. *He* II 4541[*] is weaker than in class O9. The absolute–magnitude differences are shown by the ratios λ 4068:λ 4089, λ 4119:λ 4144, λ 4387:λ 4516, and λ 4650:λ 4686.

Star	MKK	α	δ	m	HD	Notes
9 Cam	O9.5 I	04:44	$+66°10'$	4.4	B0	
δ Ori	O9.5 III	05:26	-00 22	2.5	B0	
σ Ori	O9.5 V	05:33	-02 39	3.8	B0	
ζ Ori	O9.5 III	05:35	-02 00	2.1	B0	
ζ Oph	O9.5 V	16:31	-10 22	2.7	B0	[1]
19 Cep	O9.5 I	22:02	$+61$ 48	5.2	Oe5	

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[1] The *He* I lines are exceedingly broad–considerably broader than in such Bnn stars as η UMa and γ Cas. The lines are intermediate in width between η UMa and ϕ Per. The interstellar K line appears to be abnormally strong for the spectroscopic luminosity. The line *He* II 4686 is strong on low–dispersion plates taken especially to minimize the effect of the broad lines. The spectroscopic luminosity is similar to that of σ Ori.

Table 2: Standards at O9.5

3 B0

The line at λ 4200 is very much weaker than λ 4387. *Si* IV 4089 is stronger than *Si* III 4552. The blend near λ 4650 is sharply defined on the violet side.

Star	MKK	α	δ	m	HD	Notes
γ Cas	B0 IV	00:50	$+60°11'$	var	B0p	[1]
ϕ^1 Ori	B0 III	05:29	$+09$ 25	4.5	B0	
η Ori	B0 I	05:31	-01 16	1.8	B0	
κ Ori	B0 II	05:43	-09 42	2.2	B0	
δ Sco	B0 IV	15:54	-22 20	2.5	B0	
τ Sco	B0 V	16:29	-28 01	2.9	B0	[2]

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[1] Spectrograms taken on January 6, 1941. No emission lines visible.

[2] The luminosity appears to be definitely lower than any other star in the table.

Table 3: Standards at B0

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[*] Corrected in transcription: original had *He* I .

Luminosity differences are shown by the ratios λ 4009: λ 4089, λ 4072 :λ 4089, and λ 4119:λ 4144. The line *He* II 4686 is present in class V.

4 B0.5

The blend at $\lambda\lambda$ 4640–4650 is strongest at the red edge and is intermediate in appearance between B0 and B1. *Si* III 4552 is approximately equal to *Si* IV 4089. Luminosity differences are shown by the lines of *O* II near $H\gamma$. They are very strong in the spectrum of the supergiant κ Cas. The line ratios used for luminosity classification are λ 3995:λ 4009, λ 4119:λ 4144, λ 4349:λ 4387, and λ 4416:λ 4387.

Star	MKK	α	δ	m	HD
κ Cas	B0.5 I	00:27	$+62°23'$	4.2	B0
ϵ Per	B0.5 III	03:51	+39 43	3.0	B1
139 Tau	B0.5 II	05:51	+25 56	4.9	B2
β Sco	B0.5 IV	15:59	−19 32	2.9	B1

Table 4: Standards at B0.5

5 B1

The blend at $\lambda\lambda$ 4640–4650 is fairly uniform in intensity; the red edge may still be slightly stronger, however. *Si* III 4552 is stronger than *Si* IV 4089, and the broad blend near $\lambda\lambda$ 4070–4076 is well marked. The line ratios used for luminosity classification are λ 3995:λ 4009, λ 4121:λ 4144, λ 4144:λ 4416, and λ 4387:λ 4416. The *Si* III lines and the wings of the *H* lines are also sensitive to luminosity differences.

Star	MKK	α	δ	m	HD
o Per	B1 IV	03:38	$+31°58'$	3.9	B1
ζ Per	B1 V	03:47	+31 35	2.9	B1
η Ori	B1 V	05:19	−02 29	3.4	B1
β CMa	B1 II–III	06:18	−17 54	2.0	B1
ϵ CMa	B1 II	06:54	−28 50	1.6	B1
ρ Leo	B1 I	10:27	+09 49	3.9	B0p
α Vir	B1 III–IV	13:19	−10 38	1.2	B2
σ Sco	B1 III	16:15	−25 21	3.1	B1
β Cep	B1 IV	21:27	+70 07	3.3	B1

Table 5: Standards at B1

6 B2

The blend near λ 4072 is weaker than at B1. *Si* II 4128–4130 is fainter than in class B3. The luminosity classes were determined from the ratios λ 3995:λ 4009, λ 4121:λ 4144, λ

4387:λ 4552 and from the appearance of the wings of the hydrogen lines. The stars γ Peg and ζ Cas are located between classes B2 and B3.

Star	MKK	α	δ	m	HD	Notes
γ Peg	B2.5 IV	00:08	$+14°38'$	2.9	B2	
ζ Cas	B2.5 IV	00:31	+51 21	3.7	B3	
γ Ori	B2 IV	05:19	+06 16	1.7	B2	
χ^2 Ori	B2 I	05:58	+20 08	4.7	B2p	
π Sco	B2 IV	15:52	−25 50	3.0	B2	
ρ Oph	B2 V	16:19	−23 13	5.2	B5	1
θ Oph	B2 IV	17:15	−24 54	3.4	B3	
λ Sco	B2 IV	17:26	−37 02	1.7	B2	
9 Cep	B2 I	21:35	+61 38	4.9	B2p	2
12 Lac	B2 III	22:37	+39 42	5.3	B2	

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[1] The *He* I lines are as strong as in other B2 stars and are considerably stronger than at class B5. The *H* lines are strong and broad; this has been taken to be an effect of low luminosity in a B2 spectrum rather than a reason for classifying the star as B5. The *H* lines are somewhat weaker than in η UMa (B3). All spectral lines are very broad.

[2] The star 9 Cep is a pronounced supergiant but spectroscopic evidence (λ 3995:λ 4009, λ 4387:λ 4552, intensity of *H* lines) indicates that it is definitely less luminous than χ^2 Ori.

Table 6: Standards at B2

The luminosity effects are so well marked at B2 that there is no ambiguity in the location of any of the stars in the five luminosity classes used.

7 B3

The blend *Si* II 4128–4130 is stronger than at class B2, relative to *He* I 4121. The luminosity classification depends on the ratios λ 3995:λ 4009 and λ 4121:λ 4144 and on the appearance of the wings of the *H* lines.

Star	MKK	α	δ	m	HD	Notes
ϵ Cas	B3 III	01:47	+63°11′	3.4	B3	[1]
η Aur	B3 V	04:59	+41 06	3.3	B3	
χ Aur	B3 I	05:26	+32 07	4.9	B1	
σ^2 CMa	B3 I	06:58	−23 41	3.1	B5p	
η UMa	B3 V	13:43	+49 49	1.9	B3	[2]
ι Her	B3 IV	17:36	+46 04	3.8	B3	
σ Sgr	B3 IV–V	18:49	−26 25	2.1	B3	
55 Cyg	B3 I	20:45	+45 45	4.9	B2	

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[1] The lines *He* I 4026 and 4471 are considerably weaker than in other B3 stars. The broad *H* wings observed for stars of luminosity class V are not seen.

[2] A very broad, faint K line has been observed on low–dispersion spectra of η UMa. This line appears to be definitely stellar in origin.

Table 7: Standards at B3

8 B5

The spectral type is determined from the ratio of *Si* II 4128–4130 to *He* I 4144. The luminosity class is determined from the appearance of the wings of the hydrogen lines.

Star	MKK	α	δ	m	HD
δ Per	B5 III	03:35	+47°28′	3.1	B5
η CMa	B5 I	07:20	−29 06	2.4	B5p
κ Hya	B5 V	09:35	−13 53	5.0	B3
τ Her	B5 IV	16:16	+46 33	3.9	B5
67 Oph	B5 I–II	17:55	+02 56	3.9	B5p

Table 8: Standards at B5

9 B8

The spectral type is determined principally from the ratio of *Si* II 4128–4130 to *He* I 4144. The luminosity class is determined from the appearance of the wings of the hydrogen lines.

Star	MKK	α	δ	m	HD
β Per	B8 V	03:01	+40°34′	2.2	B8
η Tau	B8 III	03:41	+23 48	3.0	B5p
β Ori	B8 Ia	05:09	−08 10	0.3	B8p
β Tau	B8 III	05:20	+28 31	1.8	B8
β CMi	B8 V	07:21	+08 29	3.1	B8
α Leo	B8 V	10:03	+12 27	1.3	B8
β Lib	B8 V	15:11	−09 01	2.7	B8

Table 9: Standards at B8

10 The Spectrum of ζ Draconis

From the lines of *He* I , *Mg* II , and *Si* II the spectral type would be judged to be B8. The Balmer lines are very peculiar; they are weak but do not have the sharp–edged appearance associated with high luminosity. A superficial examination might indicate that the star belongs in luminosity class II at B8. A comparison with the A0 Ib star η Leo shows, however, that the shape of the Balmer lines–in particular $H\delta$ and $H\epsilon$ is not similar to a high–luminosity star; the contours of the H lines are more nearly like those in an early B–type dwarf. The trigonometric parallax of ζ Dra is $0\farcs039 \pm 7$ (two modern determinations). The absolute magnitude is probably fainter than zero, and it is likely that the star lies somewhat below the main sequence.

11 The A Stars

Of all spectral types from B to M the stars of class A are the most difficult to classify. The spectral lines are weak and may be greatly broadened; in addition, the frequency with which peculiar spectra are encountered makes any sort of accurate classification a difficult problem.

When spectra of very low dispersion are used, the classification seems to be a rather simple matter. If the c–stars and peculiar objects are omitted from consideration, the growth of K with respect to the hydrogen lines from B9 to F0 appears to be smooth and rapid and a sensitive criterion of spectral type. When spectra of higher dispersion are examined, however, it is seen that the intensity of K is by no means a unique indicator of spectral type. Stars are frequently encountered whose spectra have many characteristics of class F, while the K line indicates a class of A2 or A3. To make the problem even more difficult, it appears that the colors of these stars are in disagreement with the type derived from the K line and probably correspond to the later class indicated by certain other spectral features.

From investigations of several galactic clusters by Titus it appears that these pseudocomposite spectra may have a high space frequency and a corresponding importance in problems of stellar astronomy. As the problem of their classification is of considerable importance, the spectra of several of the brightest objects of this class will be described in detail later.

In addition to these "metallic–line" A stars, there are several other groups of peculiar spectra. Stars of these classes form only a small fraction of the total, and their peculiarities can be recognized in general on low-dispersion spectrograms. It is possible, then, to eliminate them from problems in which mean absolute magnitudes or color indices are used.

The B9–F0 stars have been reclassified with the particular object of obtaining as pure a temperature sequence as is possible. In the early A subdivisions the general increase in intensity of the enhanced lines of iron and titanium appears to be closely correlated with color, while for the later subdivisions the *Mn* I blend near λ 4032 appears to be the most useful index of type on spectrograms of the dispersion used. The supergiants are discussed in another place.

12 B9

The line *He* I 4026 is weaker relative to K than in class B8. *He* I 4471 is considerably fainter than *Mg* II 4481. The luminosity classification is based on the appearance of the wings of the *H* lines.

Star	MKK	α	δ	m	HD
δ Crv	B9 V	12:24	$-15°58'$	3.1	A0
γ Lyr	B9 III	18:55	+32 33	3.3	A0p
α Peg	B9 V	22:59	+14 40	2.6	A0

Table 10: Standards at B9

13 A0

The lines of *He* I are faint or absent in the dwarfs. The strongest enhanced lines of iron are faintly present in main-sequence stars and increase in strength with increasing luminosity. The hydrogen lines show a marked negative absolute–magnitude effect.

Star	MKK	α	δ	m	HD	Notes
C Hya	A0 V	08:20	$-03°35'$	4.0	A0	
γ UMa	A0 V	11:48	+54 15	2.5	A0	
α CrB	A0 V	15:30	+27 03	2.3	A0	
α Lyr	A0 V	18:33	+38 41	0.1	A0	
δ Cyg	A0 III	19:41	+44 53	3.0	A0	[1]

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[1] The hydrogen lines in δ Cygni have less pronounced wings than in the other stars listed. Dr. Kuiper has found that the measures of the visual system made during the last 30 years indicate a dynamical parallax of 0″.013–0″.018.

Table 11: Standards at A0

The luminosity classification was made on the basis of the wings of the hydrogen lines.

14 A1

The metallic lines are stronger than at class A0. The blend *Mn* I 4030–4034 is first well seen in this class. The line λ 4385 is stronger relative to λ 4481 than in class A0.

Star	MKK	α	δ	m	HD
γ Gem	A1 V	06:31	$+16°29'$	1.9	A0
α CMa	A1 V	06:40	-16 35	-1.6	A0
α Gem A	A1 V	07:28	+32 06	2.0	A0
β UMa	A1 V	10:55	+56 55	2.4	A0

Table 12: Standards at A1

The luminosity class was determined from the appearance of the wings of the hydrogen lines. It is possible that the wings are slightly less pronounced in the spectrum of γ Gem than in the other stars listed.

15 A2

The line at λ 4385 is stronger relative to *Mg* II 4481 than in class A1. The blend at λ 4129 is considerably stronger than *Mn* I 4030–4034.

Star	MKK	α	δ	m	HD
β Aur	A2 IV	05:52	$+44^\circ 56'$	2.1	A0p
λ UMa	A2 IV	10:11	+44 25	3.5	A2
ζ UMa(br)	A2 V	13:19	+55 27	2.4	A2p
β Ser	A2 IV	15:41	+15 44	3.7	A2
η Oph	A2 V	17:04	−15 36	2.6	A2

Table 13: Standards at A2

Luminosity differences are shown by the ratios of the blends $\lambda\lambda$ 4128–4131:$\lambda\lambda$ 4171–4179, by the intensity of the blend centered near λ 4555, and by the appearance of the wings of the hydrogen lines.

16 A3

The spectral type is determined from the intensity of the blend at λ 4032 and the ratio λ 4300:λ 4385 . The luminosity class depends on the ratios λ 4416:λ 4481, λ 4175:λ 4032, and λ 4226:λ 4481, and on the appearance of the wings of the *H* lines.

Star	MKK	α	δ	m	HD	Notes
38 Lyn	A3 V	09:12	$+37^\circ 14'$	3.8	A2	
β Leo	A3 V	11:44	+15 08	2.2	A2	[1]
δ UMa	A3 V	12:10	+57 35	3.4	A2	
ζ Vir	A3 V	13:20	−00 05	3.4	A2	
γ UMi	A3 II–III	15:20	+72 11	3.1	A2	[2]
δ Her	A3 IV	17:10	+24 57	3.2	A2	[3]
α PsA	A3 V	22:52	−30 09	1.3	A3	[4]

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[1] The hydrogen lines are weaker in the spectrum of β Leo than in the other dwarfs listed.

[2] The hydrogen lines in γ UMi are narrower than in the other stars in the table; the broad wings associated with low luminosity are absent.

[3] The lines are very broad, and the classification is uncertain.

[4] α PsA gives spectroscopic evidence of having the lowest luminosity of any star in the table.

Table 14: Standards at A3

17 A5

The principal line ratio for determining the spectral type is $\lambda\lambda$ 4030–4034:$\lambda\lambda$ 4128–4132. The luminosity class is determined from the ratios λ 4417:λ 4481 and λ 4417:λ 4300.

Star	MKK	α	δ	m	HD
δ Cas	A5 V	01:19	$+50^\circ 43'$	3.0	A5
β Ari	A5 V	01:40	+20 19	2.7	A5
β Tri	A5 III	02:03	+34 31	3.1	A5
g UMa	A5 V	13:21	+55 31	4.0	A5
α Oph	A5 III	17:30	+12 38	2.1	A5

Table 15: Standards at A5

18 A7

The ratios $\lambda\lambda$ 4030–4034:$\lambda\lambda$ 4128–4132 and λ 4300:λ 4385 were used to determine the spectral type. The luminosity classes depend on the ratio λ 4417:λ 4481.

Star	MKK	α	δ	m	HD
γ Boo	A7 III	14:28	$+38^\circ 45'$	3.0	F0
α Aql	A7 V	19:45	+08 36	0.9	A5
α Cep	A7 V	21:16	+62 10	2.6	A5

Table 16: Standards at O9.5

19 F0

The spectral type is determined from the ratio $\lambda\lambda$ 4030–4034:$\lambda\lambda$ 4128–4132 and the appearance of the spectrum in the neighborhood of λ 4300. The luminosity class is determined from the relative intensity of λ 4172 and λ 4132 (red edge of broad blend) and the ratio λ 4172:λ 4226.

Star	MKK	α	δ	m	HD	Notes
ζ Leo	F0 III	10:11	$+23^\circ 55'$	3.7	F0	
γ Vir	F0 V	12:34	−00 54	2.9	F0	[1]
γ Her	F0 III	16:17	+19 23	3.8	F0	
ϵ Cep	F0 V	22:11	+56 33	4.2	F0	

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[1] The spectral type is that of the integrated light of the two components.

Table 17: Standards at F0

20 F2

The ratio of intensity $\lambda\lambda$ 4030–4034:$\lambda\lambda$ 4128–4132 is greater than in the corresponding luminosity class at F0. A shading is observed degrading toward the red from λ 4300. The luminosity class is determined from the ratios λ 4171:λ 4226 and λ 4077:λ 4045.

Star	MKK	α	δ	m	HD
β Cas	F2 III	00:03	$+58°36'$	2.4	F5
δ Gem	F2 IV	07:14	+22 10	3.5	F0
υ UMa	F2 III	09:43	+59 31	3.9	F0
78 UMa	F2 V	12:56	+56 54	4.9	F0
σ Boo	F2 V	14:30	+30 11	4.5	F0
ζ Ser	F2 IV	17:55	−03 41	4.6	F0
π Sgr	F2 II	19:03	−21 11	3.0	F2

Table 18: Standards at F2

21 The Peculiar A Stars

The most frequently encountered of the peculiar A stars are the "silicon," "strontium," and "manganese" groups and the so–called "metallic–line" stars. The spectra of the last–named consist essentially of features which seem to belong to two different spectral types and are considered separately.

The silicon and strontium stars can be identified on spectrograms of fairly low dispersion, but a satisfactory description of the details can be made only from medium– or high–dispersion spectra. Some of the brighter of the peculiar stars whose spectra can be used as prototypes are described below.

α And. – B9p. Manganese. The lines of *Mn* II are abnormally strong. On considerably widened, fine–grain spectrograms having a dispersion of 125 Å per mm at $H\gamma$ a number of peculiar faint lines are visible, which are sufficient to distinguish this type of spectrum from others.

ι Lib. – B9p. Silicon. The K line is very faint. The appearance of the wings of the H lines indicates that the star is brighter than the ordinary main–sequence stars.

θ Aur. – A0p. Silicon. The K line is exceedingly faint. The lines of *Cr* II vary in intensity. The star appears to be of luminosity class III and is brighter than the main sequence. The absolute magnitude is probably around –1 to –2.

α CVn(*brighter*). – A0p. Silicon–europium. The spectrum is exceedingly complex and requires the highest dispersion for adequate study. The lines of *Si* II and *Eu* II are both strong. Many spectral lines vary in intensity. The appearance of the wings of the hydrogen lines indicates that the star is more luminous than an ordinary A dwarf. The absolute magnitude is probably around –1 to –2.

ϵ UMa. – A0p. A number of peculiar features which distinguish the spectrum of 78 Vir are present but are in general fainter. The *Si* II lines are not abnormally strong. The K line and a number of other spectral features vary in intensity within a period of a few days. This star is the brightest of the "spectrum variables."

17 Com. – A2p. Chromium–europium. The spectrum is similar to 78 Vir. The K line is weak. The star is a member of the Coma cluster.

78 Vir. – Chromium–europium. The general level of excitation corresponds roughly to an A2 star. There may be a faint, broad K line superposed over the sharp component. The blended feature at λ 4171, indicative of strong *Cr* II, is outstanding on spectrograms of low dispersion. *Si* II is weak; the blend at λ 4I28–λ 4132 is not due principally to *Si* II but is indicative of a "europium star." The K line is weak. 78 Vir is a member of the Ursa Major cluster.

73 Dra. – Ap. Strontium–europium–chromium. A number of the lines, including λ 4077 and λ 4215, are variable in intensity. The K line is about as strong as in a normal B8 spectrum. The effective excitation is considerably lower than in α CVn and the spectrum is crowded with metallic lines.

ι **Cas. – A5p. Strontium.**

γ **Cap. – Strontium.** The spectrum can be classified as near F0 III. The strontium line at λ 4077 is abnormally strong but not so strong as in γ Equ. In both spectra the line is stronger than in any normal luminosity class at F0. There is no well–marked absolute–magnitude effect for λ 4077 at F0; this is near the place at which the effect changes from a negative one (early A–stars) to the strongly positive one observed in the F5–M stars.

γ **Equ. – Strontium–europium.** The type is near F0, but the spectrum is so peculiar that a luminosity class cannot be determined. The *Sr* II lines λ 4077 and λ 4215 are stronger than in any other F0 star observed at Yerkes. This should not, however, be taken as evidence of high luminosity, since *Sr* II is insensitive to luminosity changes near F0 and more sensitive lines do not indicate that the star is a supergiant. The blend at $\lambda\lambda$ 4128–4132 is strong, but this is not due to *Si* II. In stars later than A0 it appears to be indicative of the presence of *Eu* II.

β **CrB. – Chromium–europium.** The spectral type is near F0, but the spectrum is so peculiar that no luminosity class can be estimated. The blend at $\lambda\lambda$ 4128–4132 is very strong; this appears to be indicative of strong *Eu* II and not of abnormal strength of the *Si* II doublet. The blend at λ 4171 is strong; this is an indication of abnormal strength of *Cr* II. A considerable amount of the intensity of the line near λ 4077 is due to blended lines of *Cr* II. The lines of *Eu* II may be stronger than in any other bright star, with the possible exception of the spectrum–variable HR 5355.

Generalities. The manganese stars appear to be present at B8–B9, the silicon stars at B9–A0, the europium stars at A0–F0, and the strontium stars at A0–F0. These groups can all be identified on low-dispersion spectrograms, but any kind of detailed discussion requires higher dispersion. The bright silicon stars observed at Yerkes appear to be around, 1 or 2 mag. above the main sequence at B9 and A0. All the peculiar groups of stars lie near class A, and an association with the maximum intensity of the hydrogen lines is suggested.

22 The Metallic–Line Stars

63 Tau. The K line has an intensity about equal to a star of class A1. The general metallic–line spectrum resembles closely the star ζ Leo (F0 III). 63 Tau is in the Taurus cluster and has an absolute magnitude of +2.8. As ζ Leo is certainly much more luminous, the absolute–magnitude effect observed for 63 Tau is a false one. There seems to be no explanation of the spectrum on the basis of two normal stars.

α Gem(*ft*). The spectral type from the K line is about A1; from the metallic lines it is about A5. All lines appear to originate in one star, since α Gem(*ft*) is a spectroscopic binary with only one spectrum visible.

ζ UMa (*ft*). The spectral type from the K line is about A2 and from the metallic lines is around A7. ζ UMa (*ft*) is a member of the Ursa Major cluster and has an absolute magnitude of about +2.0.

ϵ Ser. The spectral type from the K line is near A2 and from the metallic lines about A7.

α^2 Lib. The spectral type from the K line is about A3 and from the metallic lines near A7. The absolute magnitude is probably in the neighborhood of +1.5.

ζ Lyr A. The spectral type from the K line is about A3 and from the metallic lines around A7. ζ Lyr B appears to be an ordinary main–sequence star of type F0. The intensities of the lines are closely similar to ϵ Cep.

15 UMa. The spectral type from the K line is around A3; the metallic lines appear to be fairly similar in intensity to ρ Pup (F6 II). The absolute-magnitude effect observed is probably false, as 15 UMa has a proper motion of $0''\!.132$.

τ UMa. The K line has an intensity similar to a normal A3 star. The metallic–line spectrum matches closely that of ρ Pup (F6 II). The high absolute magnitude indicated from the metallic lines is probably illusory; τ UMa has a proper motion of $0''\!.122$.

23 The Spectrum of λ Bootis

The spectral type of λ Boo is near A0, as far as can be determined. The spectral lines, while not unusually broad, are very weak, so that the only features easily visible are a weak K line and the Balmer series of hydrogen. The trigonometric parallax indicates that the star is probably located below the main sequence. The star θ Hya has similar, but less pronounced, spectral peculiarities. It may be a high–velocity star.

III The F5–M Stars

24 F5

The G band is observed as a broad absorption with the violet part of the band somewhat stronger than the red edge. *Fe* I 4045 and λ 4226 are very much weaker than Hγ and Hδ.

Star	MKK	α	δ	m	HD
α Tri	F5 III	01:47	+20°06′	3.6	F5
ξ Gem	F5 III	06:39	+13 00	3.4	F5
α CMi	F5 IV	07:34	+05 29	05	F5
110 Her	F5 IV	18:41	+20 27	4.3	F3
β Del	F5 III	20:32	+14 15	3.7	F5
ι Peg	F5 V	22:02	+24 51	4.0	F5

Table 19: Standards at F5

The most sensitive criteria of luminosity are the ratios of λ 4077 to λ 4226 and to the *Fe* I lines at λ 4045 and λ 4063.

25 F6

The G band is slightly stronger than at class F5. *Fe* I 4045 and λ 4226 are stronger relative to Hγ and Hδ.

The ratios of λ 4077 to λ 4226 and to the *Fe* lines at $\lambda\lambda$ 4045, 4063, and 4071 are sensitive criteria of luminosity, Luminosity classes III, IV, and V, which are separated from one another by about 1 mag., are distinguishable without ambiguity. Spectroscopic parallaxes of high accuracy can be determined for the low–luminosity stars of classes F5–F8.

Star	MKK	α	δ	m	HD
π^3 Ori	F6 V	04:44	+06°47′	3.3	F8
ρ Pup	F6 II	08:03	−24 01	2.9	F5
σ^2 UMa	F6 IV	09:01	+67 32	4.9	F8
θ UMa	F6 III	09:26	+52 08	3.3	F8p
τ Boo	F6 IV	13:42	+17 57	4.5	F5
ι Vir	F6 III	14:10	−05 31	4.2	F5
θ Boo	F6 IV	14:21	+52 19	4.1	F8
γ Ser	F6 IV	15:51	+15 59	3.9	F5
χ Dra	F6 V	18:22	+72 41	3.7	F8
ξ Peg	F6 III–IV	22:41	+11 40	4.3	F5

Table 20: Standards at F6

26 F8

The spectral type is determined from the ratios λ 4045:$H\delta$ and λ 4226:$H\gamma$. The most sensitive criterion of absolute magnitude is probably the ratio λ 4077:λ 4226 for normal giants and dwarfs; while in the range from supergiants to giants the ratios λ 4077:$H\delta$ and $\lambda\lambda$ 4171–4173:λ 4226 allow a very accurate luminosity classification to be made.

Star	MKK	α	δ	m	HD
50 And	F8 IV	01:30	+40°54′	4.2	G0
36 UMa	F8 V	10:24	+56 30	4.8	F5
β Vir	F8 V	11:45	+02 20	3.8	F8
θ Dra	F8 IV	16:00	+58 50	4.1	F8
υ Peg	F8 III	23:00	+22 51	4.6	G0

Table 21: Standards at F8

27 G0

The spectral type is determined from the ratios λ 4045:$H\delta$ and λ 4226:$H\gamma$. Luminosity differences are well shown by the ratios λ 4077:λ 4226, and λ 4077:λ 4045 and for the high–luminosity stars by λ 4077:$H\delta$.

Star	MKK	α	δ	m	HD	Notes
η Cas A	G0 V	00:43	+57°17′	3.6	F8	
δ Tri	G0 V	02:10	+33 46	5.1	G0	
ι Per	G0 V	03:01	+49 14	4.2	G0	
χ^1 Ori	G0 V	05:48	+20 15	4.6	F8	
ϵ Hya	G0 III	08:41	+06 47	3.5	F8	[1]
47 UMa	G0 V	10:53	+40 58	5.1	G0	
ξ UMa	G0 V	11:12	+32 06	3.9	G0	[2]
β CVn	G0 V	12:29	+41 54	4.3	G0	
β Com	G0 V	13:07	+28 23	4.3	G0	
η Boo	G0 IV	13:49	+18 54	2.8	G0	
ζ Her	G0 IV	16:37	+31 47	3.0	G0	

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[1] The absorption extending toward the violet from λ 4215 is faintly present.

[2] Integrated light of system.

Table 22: Standards at G0

28 G2

The spectral type is determined by the ratios λ 4045:$H\delta$ and λ 4226:$H\gamma$. Luminosity line ratios are λ 4077:λ 4226 and λ 4077:λ 4045.

Star	MKK	α	δ	m	HD
λ Aur	G2 IV–V	05:12	$+40^\circ 01'$	4.9	G0
β Lep	G2 II	05:24	−20 50	3.0	G0
μ Cnc	G2 IV	08:01	+21 52	5.4	G0
λ Ser	G2 V	15:41	+07 40	4.4	G0
η Peg	G2 II–III	22:38	+29 42	3.1	G0
π Cep	G2 III	23:04	+74 51	4.6	G5

Table 23: Standards at G2

29 G5

The spectral type (except for the supergiants) is determined from the ratios λ 4144:$H\delta$ and λ 4096:$H\delta$ and the blend at λ 4030–4034: the violet side of the G band. On spectrograms of low dispersion $H\delta$ appears to be stronger in dwarfs of this class than in giants and sub–giants.

Star	MKK	α	δ	m	HD	Notes
μ Cas	G5 V	01:01	$+54^\circ 26'$	5.3	G5	[1]
κ Cet	G5 V	03:14	+03 00	5.0	G5	
o UMa	G5 II	08:22	+61 03	3.5	G0	
β Crv	G5 II	12:29	-22 51	2.8	G5	
γ Hya	G5 III	13:13	-22 39	3.3	G5	
70 Vir	G5 IV–V	13:23	+14 19	5.2	G0	[2]
β Her	G5 II–III	16:25	+21 42	2.8	K0	
η Her	G5 III	16:39	+30 07	3.6	K0	
μ Her	G5 IV	17:42	+27 47	3.5	G5	
ξ Her	G5 III	17:53	+29 16	3.8	K0	

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[1] Considerably fainter spectroscopically than other dwarfs in table.

[2] The star appears to be definitely less luminous than μ Her.

Table 24: Standards at G5

Absolute–magnitude effects are shown by the ratios λ 4226:λ 4077, λ 4063:λ 4077, λ 4144:λ 4077, λ 4085:λ 4077, λ 4250:λ 4215, λ 4226:λ 4045, and the relative intensity of the continuous spectrum on each side of λ 4215.

30 G8

The spectral type (except for the supergiants) is determined from the ratios λ 4144:$H\delta$ and λ 4096:$H\delta$ and the ratio of the blend at $\lambda\lambda$ 4030–4034 to the violet side of the G band. On the spectrograms used, $H\delta$ appears to be stronger in dwarfs of this class than in giants and subgiants.

Star	MKK	α	δ	m	HD	Notes
τ Cet	G8 V	01:39	$-16°28'$	3.7	K0	
δ Lep	G8 pec	05:47	-20 53	3.9	K0	[1]
ι Gem	G8 III	07:19	+28 00	3.9	K0	
κ Gem	G8 III	07:38	+24 38	3.7	G5	
α UMa	G8 II–III	10:57	+62 17	2.0	K0	
61 UMa	G8 V	11:35	+34 46	5.5	G5	
S 3582	G8 V	11:47	+38 26	6.5	G5	
ϵ Vir	G8 III	12:57	+11 30	3.0	K0	
ξ Boo A	G8 V	14:46	+19 31	4.8	G5	
β Boo	G8 III	14:58	+40 47	3.6	G5	
δ Boo	G8 III	15:11	+33 41	3.5	K0	
ϵ Oph	G8 III	16:13	-04 27	3.3	K0	
η Dra	G8 III	16:22	+61 44	2.9	G5	
δ Dra	G8 III	19:12	+67 29	3.2	K0	
κ Cyg	G8 III	19:14	+53 11	4.0	K0	
β Aql	G8 IV	19:50	+06 09	3.9	K0	
ζ Cyg	G8 II	21:08	+20 49	3.4	K0	
μ Per	G8 III	22:45	+24 04	3.7	K0	
λ And	G8 III–IV	23:32	+45 55	4.0	K0	

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[1] The luminosity criteria of this high-velocity star are conflicting. The ratio λ 4071:λ 4077 indicates a giant, while the *CN* break at λ 4215 is is almost invisible, as in class IV–V.

Table 25: Standards at G8

Some of the most important luminosity line ratios are λ 4045:λ 4077, λ 4063:λ 4077, and λ 4144: λ 4077. The break in the continuous spectrum at λ 4215 is one of the most sensitive discriminants of absolute magnitude. Other features are noted on the *Atlas* print.

31 K0

Spectral type is determined from the ratios $\lambda\lambda$ 4030–4034:λ 4300, λ 4290:λ 4300, and $H\delta$:λ 4096. Luminosity differences are shown by the ratios λ 4063:λ 4077, λ 4071:λ 4077, λ 4144:λ 4077, and by the intensity difference of the continuous spectrum on each side of λ 4215.

Star	MKK	α	δ	m	HD	Notes
54 Psc	K0 V	00:34	$+20^\circ 43'$	6.1	K0	
α Cas	K0 II–III	00:34	+55 59	2.3	K0	
δ Eri	K0 Iv	03:38	−10 06	3.7	K0	[1]
δ Aur	K0 III	05:51	+54 17	3.9	K0	
β Gem	K0 III	07:39	+28 16	1.2	K0	
ζ Hya	K0 III	08:50	+06 20	3.3	K0	
λ Hya	K0 III	10:05	−11 52	3.8	K0	
γ Leo A	K0 pec	10:14	+20 21	2.6	K0	[2]
46 LMi	K0 III–IV	10:47	+34 45	3.9	K0	
ν Oph	K0 III	17:53	−09 46	3.5	K0	
70 Oph A	K0 V	18:00	+02 31	4.3	K0	
η Ser	K0 III–IV	18:16	−02 55	3.4	K0	
σ Dra	K0 V	19:32	+69 29	4.8	K0	
η Cyg	K0 III	19:52	+34 49	4.0	K0	
52 Cyg	K0 III	20:41	+30 21	4.3	K0	
ϵ Cyg	K0 III	20:42	+33 36	2.6	K0	
η Cep	K0 IV	20:43	+61 27	3.6	K0	
ι Cep	K0 III	22:46	+65 40	3.7	K0	
107 Psc	K1 V	01:37	+19 47	5.3	G5	
θ Her	K1 II	17:52	+37 16	4.0	K0	
γ Cep	K1 IV	23:35	+77 04	3.4	K0	

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[1] The spectrum indicates a lower luminosity than η Cep.

[2] Luminosity criteria are conflicting. From the ratio λ 4063:λ 4077 γ Leo A would be judged more luminous than β Gem (class III), while the intensity of the *CN* break at λ 4215 is less than in stars of class III. The double star γ Leo is a high–velocity system, and the spectral peculiarities are similar to those of the high–velocity stars α Boo and δ Lep.

Table 26: Standards at K0 and K1

32 K2

The spectral type is determined from the ratios λ 4290:λ 4300 and λ 4226:λ 4325. Absolute–magnitude differences are shown by the ratios λ 4063:λ 4077 and λ 4071:λ 4077, and the break in the continuous spectrum at λ 4215.

Star	MKK	α	δ	m	HD	Notes
S 222	K2 V	00:43	$+04°46'$	5.8	G5	
ϵ Eri	K2 V	03:28	-09 48	3.8	K0	
ν Hya	K2 III	10:44	-15 40	3.3	K0	
ψ UMa	K2 III	11:04	$+45$ 02	3.2	K0	
χ UMa	K2 III	11:40	$+48$ 20	3.9	K0	
ϵ Cry	K2 III	12:05	-22 04	3.2	K0	
α Boo	K2 pec	14:11	$+19$ 42	0.2	K0	1
ι Dra	K2 III	15:22	$+59$ 19	3.5	K0	
α Ser	K2 III–IV	15:30	$+06$ 44	2.8	K0	
κ Oph	K2 III	16:52	$+09$ 32	3.4	K0	
β Oph	K2 III–IV	17:38	$+04$ 37	2.9	K0	
κ Lyr	K2 III	18:16	$+36$ 01	4.3	K0	
109 Her	K2 III	18:19	$+21$ 43	3.9	K0	
ϵ Aql	K2 III	18:55	$+14$ 56	4.2	K0	

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[1] The spectral type is slightly earlier than the mean for class K2. The luminosity criteria are conflicting; from the intensity of λ 4077 relative to neighboring *Fe* lines a luminosity class of III or even slightly brighter would be obtained, while the *CN* break at λ 4215 is considerably weaker than in other stars of class III. α Bootis is a high–velocity giant and the spectral peculiarities observed are similar to those in the case of the high–velocity giants δ Lep and Boss 2527.

Table 27: Standards at K2

The mean absolute magnitude of stars of class III is probably somewhat brighter than in types G5–K0.

33 K3

The spectral type is determined from the ratios λ 4226:λ 4325 and λ 4290:λ 4299. Luminosity classes are determined from the ratios λ 4071:λ 4077, λ 4063:λ 4077, λ 4045:λ 4077, λ 4260:λ 4215 and λ 4325:λ 4340.

Star	MKK	α	δ	m	HD
δ And	K3 III–IV	00:34	$+30°19'$	3.5	K2
ι Aur	K3 II	04:50	$+33$ 00	2.9	K2
α Hya	K3 III	09:22	-08 14	2.2	K2
ρ Boo	K3 III	14:27	$+30$ 49	3.8	K0
ϵ CrB	K3 III	15:53	$+27$ 10	4.2	K0
π Her	K3 II	17:11	$+36$ 55	3.4	K5
λ Her	K3 III	17:26	$+26$ 11	4.5	K0
α Sct	K3 III	18:29	-08 19	4.1	K0
1 Lac	K3 III	22:11	$+37$ 15	4.2	K0
S 7259	K3 V	23:08	$+56$ 37	5.7	K2

Table 28: Standards at K3

The mean absolute magnitude of the stars of luminosity class III is probably higher than at type K0. No subgiants were observed at K3.

34 K5

The spectral type is determined from the ratios λ 4226:λ 4325, λ 4290:λ4299, and λ 4383:λ 4406. Luminosity classes are determined from the ratios λ 4063:λ 4077 and λ 4260:λ 4215.

Star	MKK	α	δ	m	HD
α Tau	K5 III	04:30	$+16°18'$	1.1	K5
β Cnc	K5 III	08:11	+09 30	3.8	K2
β UMi	K5 III	14:51	+74 34	2.2	K5
γ Dra	K5 III	17:54	+51 30	2.4	K5
61 Cyg A	K5 V	21:02	+38 15	5.6	K5

Table 29: Standards at K5

The mean absolute magnitude of the stars of class III is probably brighter than at type K0. No subgiants were observed at K5.

35 The M Stars

Discussion of the M dwarfs is outside the range of the present *Atlas*. Since no stars have been observed intermediate between M dwarfs and giants, the latter can be considered separately.

The titanium oxide bands in the photographic region increase smoothly in intensity with decreasing temperature, and spectral classification from the intensity of the bands is a temperature classification (Pl. 52). The four stars illustrated in Plate 51 as standards of the M–giant sequence are on the Mount Wilson system. We are greatly indebted to Dr. Joy for checking our types at Mount Wilson. He has noted that some M stars probably vary slightly in spectral type, so that some of the standards illustrated may have a slightly different appearance at times.

The absolute magnitudes of some of the giant M stars have been discussed recently by Keenan[2] and the details of the luminosity classification are given there. Keenan's spectral types require systematic corrections to reduce them to the Mount Wilson system. Some luminosity effects in the early M giants are illustrated in Plate 53.

Table 30 gives a selection of stars whose luminosity classes have been taken from Keenan's paper. The spectral types are from the Mount Wilson catalogue of spectroscopic parallaxes. Luminosity line ratios are λ 4045:λ 4077, λ 4215:λ 4250, λ 4376:λ 4383 and λ 4383: λ 4390.

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[2] *Ap.J.*,**95**,461,1942.

Star	MW+Kn	α	δ	m	HD	Notes
RW Cep	M0: Ia	22:19	+55°27′	6.2–7.6*	Ma	[1]
μ Cep	M2 Ia	21:40	+58 19	4.4*	Ma	
SU Per	M4 Ia–Ib	02:15	+56 09	7.3*	Ma	
α Ori	M2 Ib	05:49	+07 23	0.9*	Ma	
α Sco	M1 Ib	16:23	−26 13	1.2	Ma	
5 Lac	M0 II	22:25	+47 12	4.6	K0	
π Aur	M3 II	05:52	+45 56	4.6	Ma	
β Peg	M2 II–III	22:58	+27 32	2.6*	Ma	
χ Peg	M2 III	00:09	+19 39	4.9	Ma	
β And	M0 III	01:04	+35 05	2.4	Ma	
η Gem	M3 III	06:08	+22 32	3.7*	Ma	

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*Light Variable

[1] The spectrum indicates that the absolute magnitude is brighter than μ Cep. Spectral type by Keenan.

Table 30: Standard M Giants

IV The Supergiants of Classes B8–M2

The general appearance of the spectra of the supergiants of types A–K is different from that of stars of lower luminosity; and, when an attempt is made to classify the high–luminosity stars by the ratios used for ordinary giants and dwarfs, a number of difficulties are encountered. Ratios which include a hydrogen line are strongly affected by absolute–magnitude effects in classes B8–F0 and G8–K5; in the first spectral interval the H lines are greatly weakened in the supergiants, and in the second they are considerably strengthened. The lines used to classify the A5–F5 spectra are disturbed by blends in the supergiants which have a marked absolute–magnitude effect. In addition, the G band appears as a fairly continuous absorption only for types later than F8 in the supergiants; while in ordinary giants and dwarfs it is present at F5 on plates similar to the ones used in preparing the *Atlas*.

For these reasons, if a highly accurate system is to be defined for supergiants and cepheids, it is important to set up a sequence of standard supergiants by criteria suitable for the high–luminosity stars. The system defined by the supergiants in Table 31 is in fairly good systematic agreement with the *Henry Draper Catalogue*. The stars listed define the system accurately to about a tenth of a class, except in the case of the late A and early F subdivisions, where the accuracy is appreciably lower.

Some ratios useful in determining the spectral type of the super–giants are: λ4128–λ 4130:λ 4172–λ 4179 (A0–F0), λ 4226:$H\delta$ (F5–G5), λ 4045:$H\delta$ (F5–G8), λ 4226:$H\gamma$ (F5–K5), λ 4325:$H\gamma$ (F5–G2), blend at λ 4176: blend at λ 4200 (G5–K5), λ 4383:λ 4406 (G8–K5), and the appearance of the region of the G band (F0–K5).

No stars have been classified as Ia between F8 and M2; it is possible that certain luminous irregular variable stars may belong to this class in the G and K types. It is also possible that stars of the highest luminosity develop *TiO* bands at slightly lower temperatures than the F8 Ia stars δ CMa and ρ Cas; they might then be classified among the M stars, while their line spectra correspond to class G or K.

Star	MKK	α	δ	m	HD	Notes
β Ori	B8 Ia	05:09	−08°19′	0.3	B8p	
4 Lac	B8 Ib	22:20	+48 58	4.6	B8p	
σ Cyg	B9 Ia	21:13	+38 59	4.3	A0p	
HR 1040	A0 Ia	03:21	+58 32	4.8	A0p	[1]
13 Mon	A) Ib	06:27	+07 24	4.5	A0p	
η Leo	A0 Ib	10:01	+17 15	3.6	A0p	
α Cyg	A2 Ib	20:38	+44 55	1.3	A2p	
ν Cep	A2 Ia	21:42	+60 40	4.5	A2p	
ϕ Cas	A5 Ia	01:13	+57 42	5.3	F5p	
ϵ Aur	F0 Ia	04:54	+43 41	(3.3)	F5p	
α Lep	F0 Ib	05:28	−17 54	2.7	F0	
α Per	F5 Ib	03:17	+49 30	1.9	F5	
δ CMa	F8 Ia	07:04	−26 14	2.0	F8p	
ρ Cas	F8 Ia	23:49	+56 57	(4.4)	F8p	
γ Cyg	F8 Ib	20:18	+39 56	2.3	F8p	
β Aqr	G0 Ib	21:26	−06 01	3.1	G0	
ϵ Leo	G0 I–II	09:40	+24 14	3.1	G0p	
α Aqr	G1 Ib	22:00	−00 48	3.2	G0	
ζ Cap	G4 Ib?	21:21	−22 51	3.9	G5p	[2]
9 Peg	G5 Ib	21:39	+16 53	4.5	G5	
ϵ Gem	G8 Ib	06:37	+25 14	3.2	G5	
56 Peg	G8 Ib	23:02	+24 56	5.0	K0	
ζ Cep	K1 Ib	22:07	+57 42	3.6	K0	
ϵ Peg	K3 Ib	21:39	+09 25	2.5	K0	
γ Aql	K3 I–II	19:41	+10 22	2.8	K2	
ξ Cyg	K5 Ib	21:01	+43 32	3.9	K5	
α Sco	M1 Ib	16:23	+26 13	1.2	Ma	[3]
μ Cep	M2 Ia	21:40	+58 19	var	Ma	[3]
α Ori	M2 Ib	05:49	+07 23	var	Ma	[3]

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[1] The *H* lines are slightly stronger than in β Ori.

[2] The line *Sr* II 4077 is very strong.

[3] The Mount Wilson spectral types of the M giants have been assumed.

Table 31: The Supergiants of Classes B8–M2

V Five Composite Spectra

γ **Per.** From the ratios λ 4045:$H\delta$ and λ 4226:$H\gamma$ and the intensity of the G band a spectral type of F6 is derived on the system of the present *Atlas*. The following features indicate that the spectrum in the blue region comes from two stars.

1. The *CN* absorption, having a sharp head at λ 4215, is present and is about as strong as in a giant G2 star. This absorption was not seen in any normal star earlier than G0 examined while preparing the *Atlas.*
2. There is a broad, faint absorption at $H\delta$ which makes the appearance of the region different from that in a normal F6 star. This is probably due to a broad A–type hydrogen line superposed on the narrower one.
3. The strongest absorption at K is narrow and is similar to a star near type A5, and there is almost certainly present a faint, broad K line superposed on the sharp one.

   The spectral type of the component of later type is probably near G5. Its luminosity class is probably III.

α **Equ.** The spectrum is similar to γ Per. The *CN* absorption toward the violet from λ 4215 is present and indicates that the later–type spectrum is near G5. The integrated spectral type at $\lambda\lambda$ 4000–4300 is somewhat earlier than γ Per–about F5–owing to the greater strength of the *H* lines. The A star appears to be somewhat brighter relative to the later–type component. The line at λ 4077 is stronger relative to λ 4045 than in γ Per.

o **Leo.** The *CN* absorption near λ 4215 is not observed and the later–type spectrum is therefore almost certainly earlier than G0. This spectrum is combined with one of early type which, to judge by the narrow K line, is near class A2. The two components form a spectroscopic binary. The spectrograms used were obtained on April 22, 1942; on them the K line is composite, the sharp A component lying near the red edge of a faint, diffuse component. The line λ 4077 is strong, and from its intensity a similarity in luminosity to an F supergiant [α Per (F5) or γ Cyg (F8)] might be assumed. The region of the G band, however, does not have an appearance like that of a supergiant of type F, and other line ratios suggest a luminosity class of around II–III. This value is uncertain; it could be determined more accurately if spectrograms on a high–contrast emulsion were available. The spectral type of the component of later type is probably near F6.

α **Aur.** The combined spectral type of the two components is G2 II–III. An unpublished determination made several years ago from high–dispersion plates on which the components were resolved gives, on the system of the present *Atlas*,

Spectral type of primary	G5
Spectral type of secondary	F6
Combined spectral type	G2 II–III

The separate values for the two components are very uncertain and may be in error by a considerable fraction of their separation.

β **Cyg.** The spectral type of the component of late type is probably K3 II. At the position of K there is a broad, shallow absorption. It is estimated that the spectral type of the component of early type is probably earlier than A0. The features described all belong to the spectrum of β Cyg A.

VI Conclusion

The relation between the revised types of the B2–G0 dwarfs and color is shown in Figure 1. An approximate calibration of the luminosity classes is given in Figure 2. While any definitive calibration requires the use of many more stars than are considered here, we do not think that any of the curves should be in error anywhere by much more than a half–magnitude.

Since about a year was needed for the making of the photographic prints for the *Atlas*, there is a difference in epoch of that time between the classification as illustrated there and as expounded here. It was unavoidable that certain improvements and alterations should have suggested themselves in the interim. These have been incorporated in the text; and there are therefore several discrepancies between the *Atlas* plates and the text. In all such cases the text is to be taken as final, and the data on the Atlas prints should be altered to agree with the outline. The most important of the changes has been the shifting in spectral type of two standard stars. These are μ Peg (Pls. 36, 41, 44), whose type should be changed from G5 to G8, and σ^2 UMa (Pl. 37), whose type has been altered from F8 to F6.

The characteristics of the system described here can be summarized as follows: The two–dimensional classification can be used to describe accurately the spectra of the normal stars brighter than the eighth apparent magnitude. Since this includes all but a very small percentage of the total number of stars brighter than that limiting magnitude, it is possible to derive from the extension of the classification to fainter objects certain general information concerning the distribution in space of the stars absolutely brighter than the sun.

In the course of the investigation several interesting details have been noted. Among the Be stars very broad absorption lines have been observed, which suggest maximum stellar rotational velocities somewhat higher than those found earlier. The most striking example of this is the star ϕ Per. Other stars having lines suggesting higher rotational velocities than the Bnn star, η UMa, are ζ Oph, 25 Ori, and β Mon A.

Also of interest is the discovery of similar spectral peculiarities in several G– and K–type high–velocity giants. The high–velocity stars δ Lep, Boss 2527, γ Leo, and probably α Boo have similar peculiar features. The most striking of these on low dispersion is the abnormal weakness of the *CN* absorption extending toward the violet from λ 4215.

When carefully calibrated, the luminosity classification should allow the determination of accurate spectroscopic parallaxes on low–dispersion plates of stars of all classes from O9 to M2 (with the possible exception of classes B8–A2).

The spectral classification defines with accuracy a system of color standards which can be used in investigations of interstellar absorption and determinations of systematic errors in spectral classification of faint stars. It should be emphasized that the actual features used for classification are dependent on the dispersion used and that some or most of the criteria listed here might be unsuitable for use on spectra having greatly different dispersion.

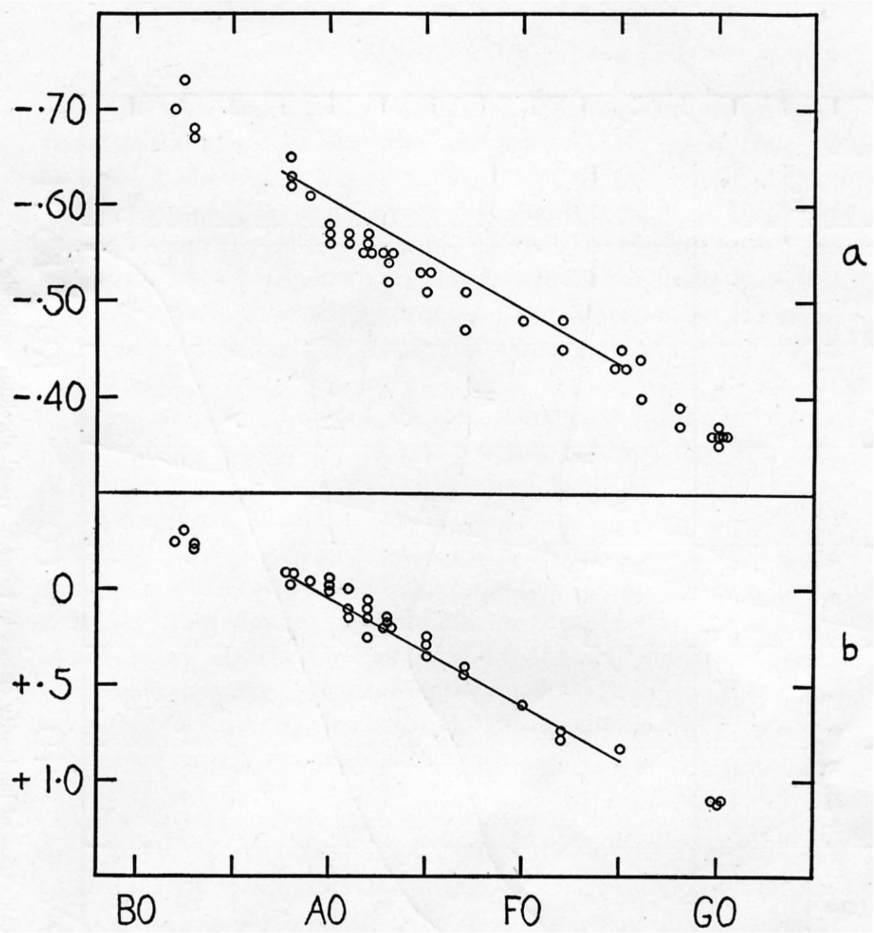

Figure 1: Color equivalents of B2–G0 main–sequence stars. The photoelectric color indices of Bottlinger (above) and Greenwich gradients (below) are plotted against the spectral types of the present *Atlas.* The stars included are those of luminosity classes IV and V which appear to be definitely less than 100 parsecs distant from the sun. The same stars are plotted in the two diagrams for types earlier than F5. Stars of class V only are shown for classes F6–G0. The multiple system ξ UMa has not been plotted. The two relationships between color equivalent and spectral type are not similar; a simple change of zero point and scale will not suffice to change one color system to the other. There is a marked depression in the curve for the early A stars in (a) which is not present in (b). The curve in (a) is definitely concave upward from B8 to F5, while it is sensibly linear in (b). This difference is interpreted as an effect of the hydrogen lines on the violet wave lengths for the photoelectric color indices. The same effect is present to a varying degree in other catalogues of color equivalents. The two straight lines connect the centers of gravity at B8–B9 and F0–F5. In the G and K stars other spectral features appear to affect observed color equivalents. In particular, the strong absorption due to *CN* in giants tends to increase the color differences between giants and dwarfs observed with short base–line photoelectric color indices. In the K stars of high luminosity a heavy absorption extending toward the violet from the vicinity of λ 4300 cannot fail to have an appreciable effect on colors determined in this region.

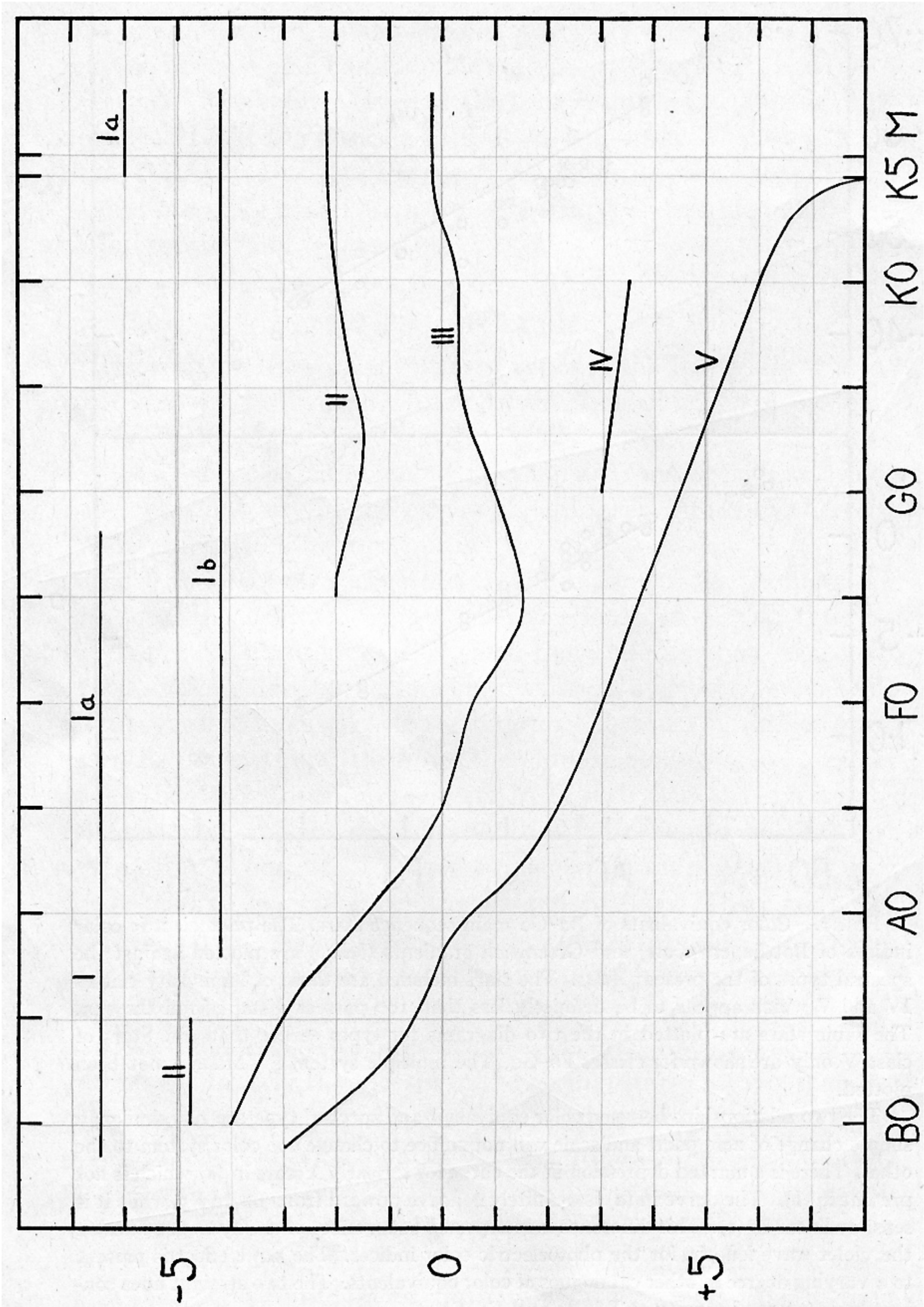

Figure 2: Preliminary calibration of luminosity classes in terms of visual absolute magnitude.

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YERKES OBSERVATORY
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