Astrophys. monographs, Univ. Chicago Press (1943)

AN ATLAS OF STELLAR SPECTRA

WITH AN OUTLINE OF SPECTRAL CLASSIFICATION

Morgan * Keenan * Kellman

Table of Contents

Next

1. 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 types - 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. Fecker, 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 Hβ ($\lambda\lambda$ 3920-4900).

The dispersion used (125 A per mm at Hγ) 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 A per mm.

The lowest dispersion capable of giving high accuracy for objective-prism spectra is greater; the limit is probably near 100 A per mm. The minimum dispersion with which an entirely successful two-dimensional classification on objective-prism plates can be made is probably near 140 A 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 supergiants, 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 supergiants and ordinary giants.

Next Contents

2. THE O5-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 A 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 A 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 A 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 Hγ and Hδ. With plates of higher dispersion a corresponding reduction in the magnifying power of the viewing eyepiece should be made. For spectra later than Fo a width of about one-sixth the distance between Hγ and Hδ is sufficient, unless the dispersion is less than 125 A 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 extrafocal images in stellar photometry.

TABLE 1.
CLASSIFICATION OF THE O STARS

Star	Sp_{MKK}	Sp_{HHP}	*a*	δ	*m*	HD	Notes
ζ PUP..........	O5	....	8:00	-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	....	0:47	+56 5	7.7	B2	1
θ^1 Ori C........	O6	O7	5:30	- 5 27	5.4	Oe5	2

HD 165052...	O7	O6	17:59	-24 24	6.8	Oe5	1
S Mon...........	O7	O7	6:35	+9 59	4.7	Oe5	
ξ Per.............	O7	....	3:52	+35 30	4.1	Oe5	
λ Ori A.........	O8	O8	5:29	+9 52	3.7	Oe5	
ι Ori..............	O9 V	O9	5:30	-5 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

NOTES

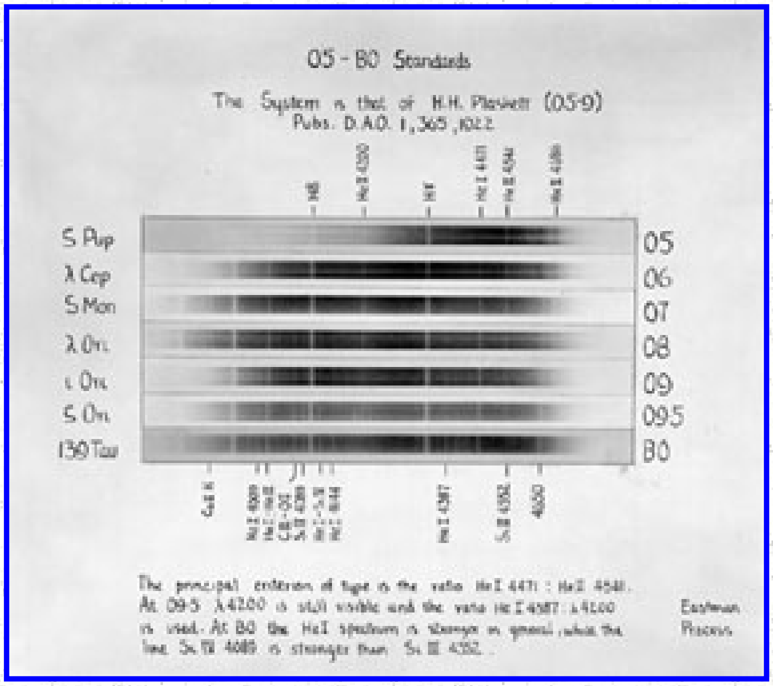
1. No emission lines visible on low-dispersion spectrograms. *He* II 4686 is much stronger than λ 4650.
2. The *H* lines are abnormally broad in comparison to other absorption lines.
3. Main-sequence star. Luminosity differences at O9 are shown by the following ratios: λ 4068: λ 4089, λ 4387: λ 4541, and λ 4650: λ 4686.
4. O-type supergiants.

Next Contents Previous

1. The O Stars

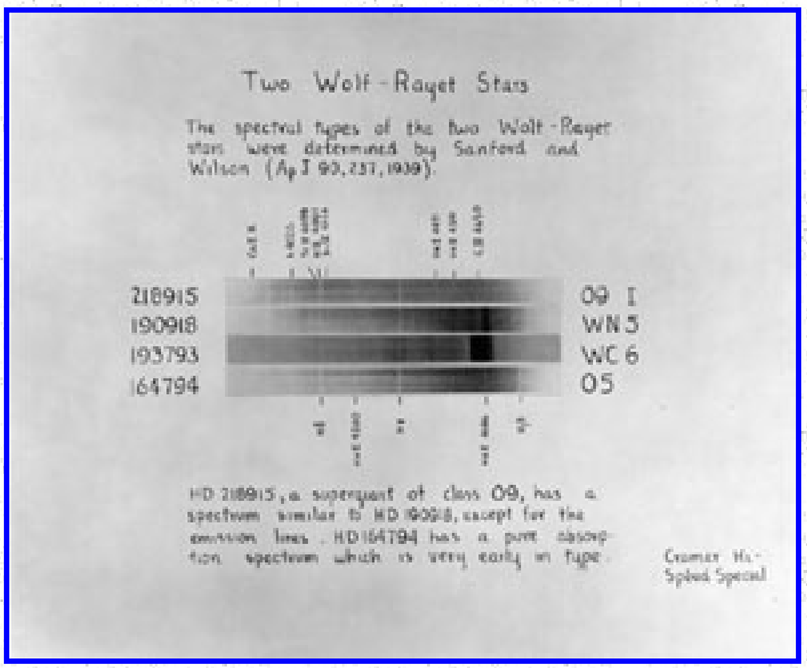
No luminosity classification has been attempted for stars earlier than O9. The spectral type has been determined from the ratio *He* I 4471: *He* II 4541. The types determined from this ratio appear to be consistent with the appearance of other spectral features in a sequence of effective excitation.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

Plate 1. O5 - B0 Standards



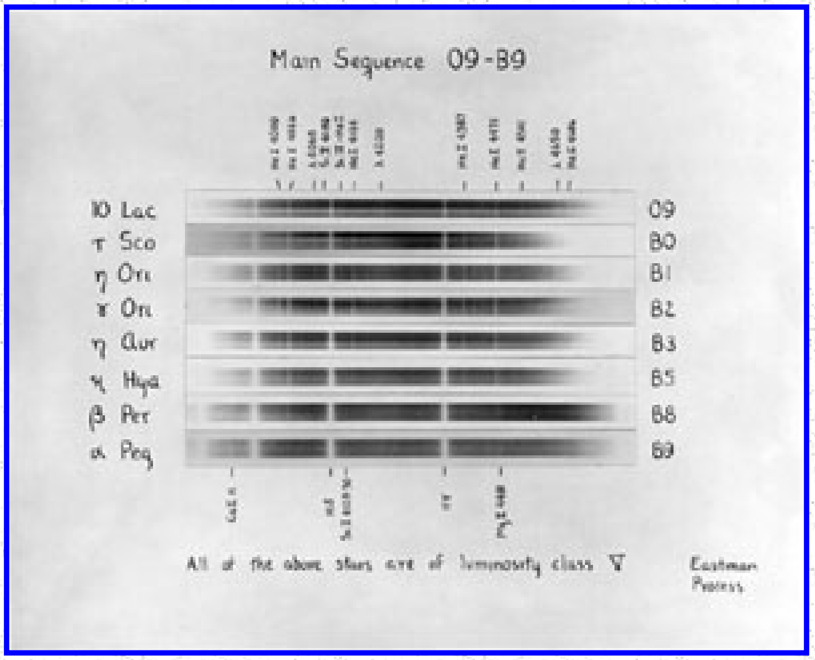
If the spectral types of the O stars are determined from the single ratio of the absorption lines *He* I 4471: *He* II 4541, results accurate to a tenth of a class between O5 and O9 can be obtained on plates of the dispersion used (125 A per mm at Hγ). This single ratio appears to be the most useful 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; the number of stars in this class is very small, and individual description of each spectrum seems to be necessary.

Plate 2. Two Wolf-Rayet Stars



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.

Plate 3. Main Sequence O9 - B9



---

1 *Pub. Dom. Ap. Obs.*, **1**, 365, 1922. Back.

Next Contents Previous

2. O9.5

At class O9.5 the line at λ 4200 is intermediate in intensity between O9 and B0. *He* I 4541 is weaker than in class O9.

Plate 4. Supergiants O9.5 - A0

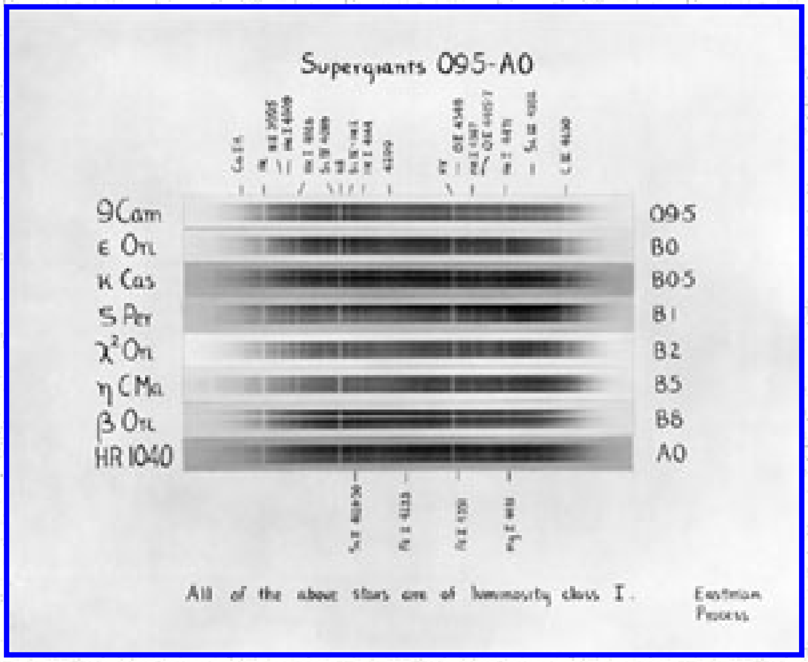


TABLE 2
STANDARDS AT O9.5

Star	MKK	*a*	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	

NOTES

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.

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.

Plate 5. Luminosity Effects at O9

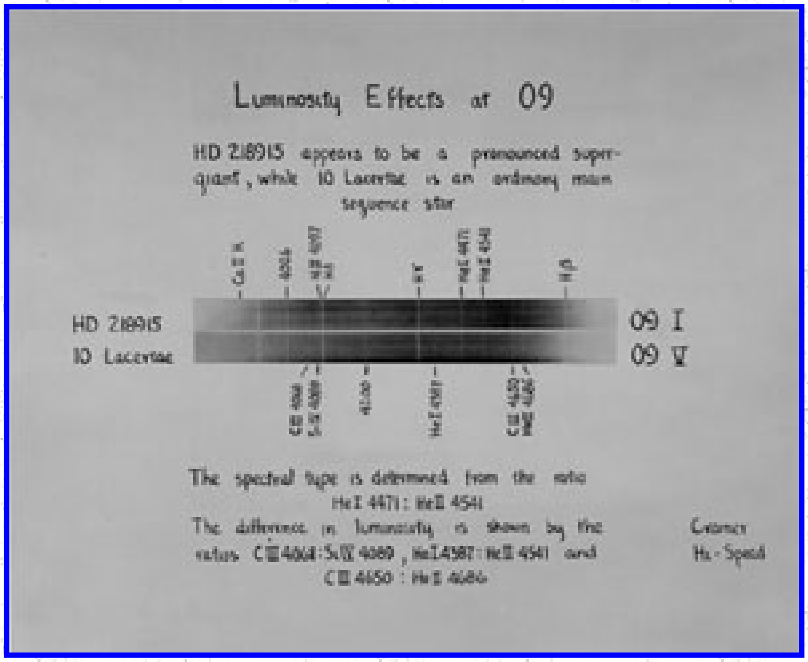
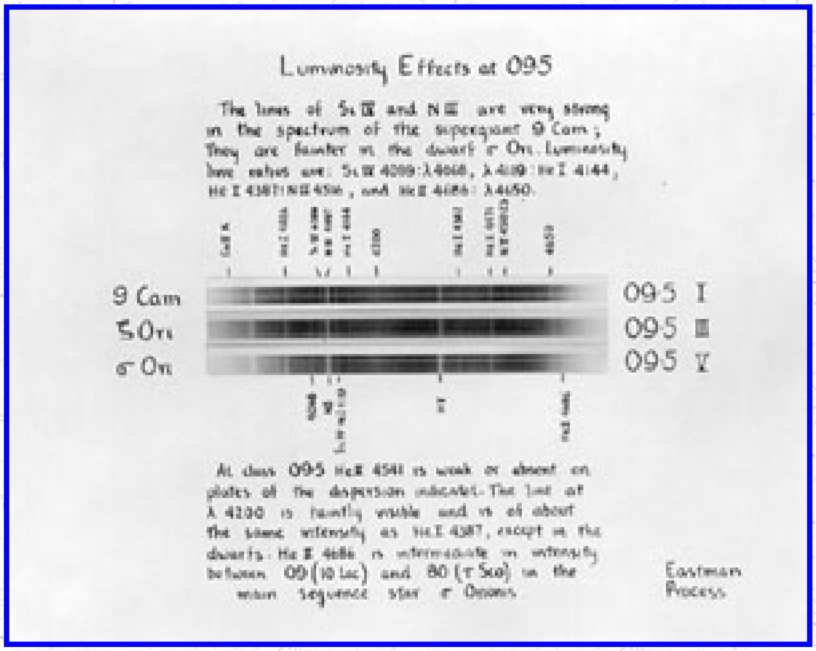


Plate 6. Luminosity Effects at O9.5



Next Contents Previous

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.

TABLE 3
STANDARDS AT B0

Star	MKK	RA	DEC	*m*	HD	Notes
γ Cas....	B0 IV	00:50	+60° 11'	var	B0p	1
φ1 Ori...	B0 III	05:29	+ 9 25	4.5	B0	
ε Ori.....	B0 I	05:31	- 1 16	1.8	B0	
κ Ori....	B0 II	05:43	- 9 42	2.2	B0	
δ Sco....	B0 IV	15:54	-22 20	2.5	B0	
τ Sco....	B0 V	16:29	-28 1	2.9	B0	2

NOTES

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.

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.

Plate 7. Luminosity Effects at B0

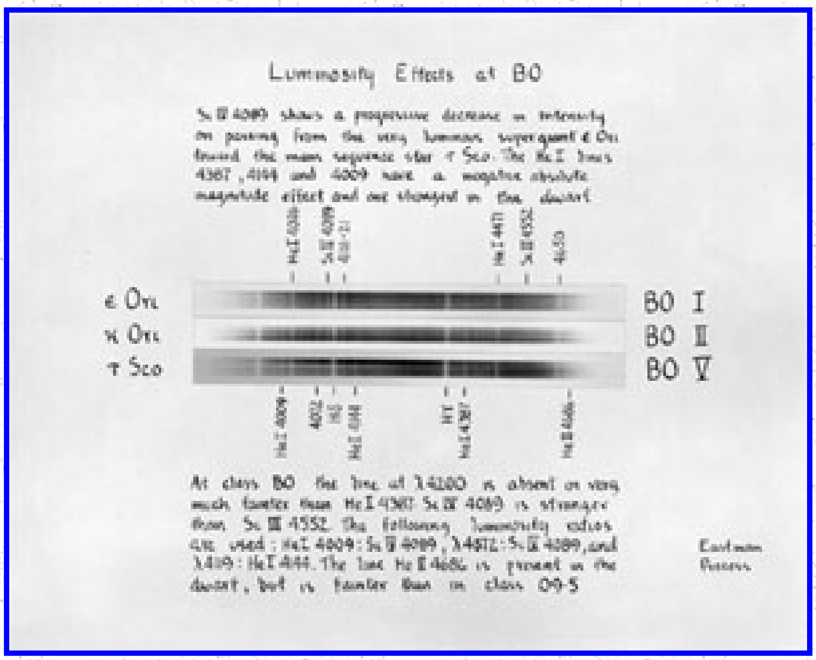
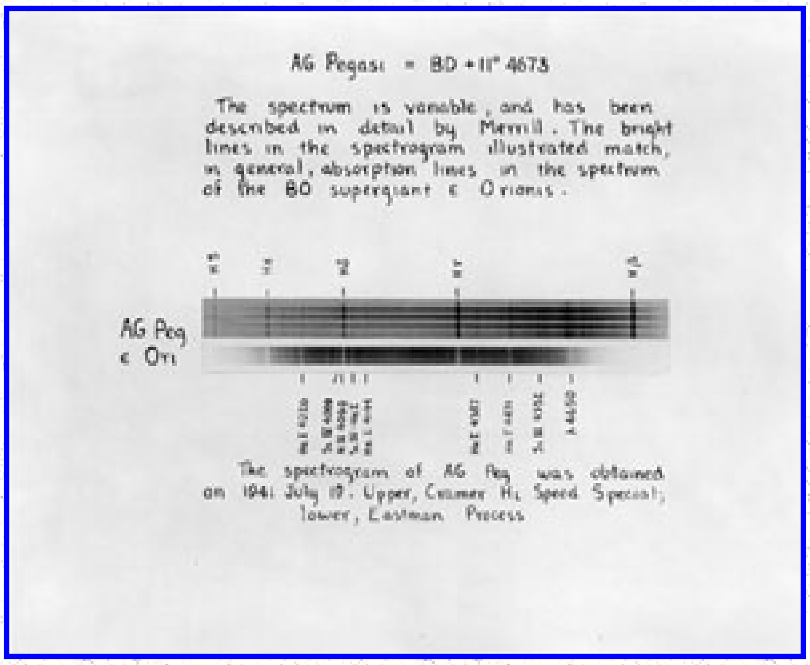


Plate 8. AG Pegasi = BD 11 4673



Next Contents Previous

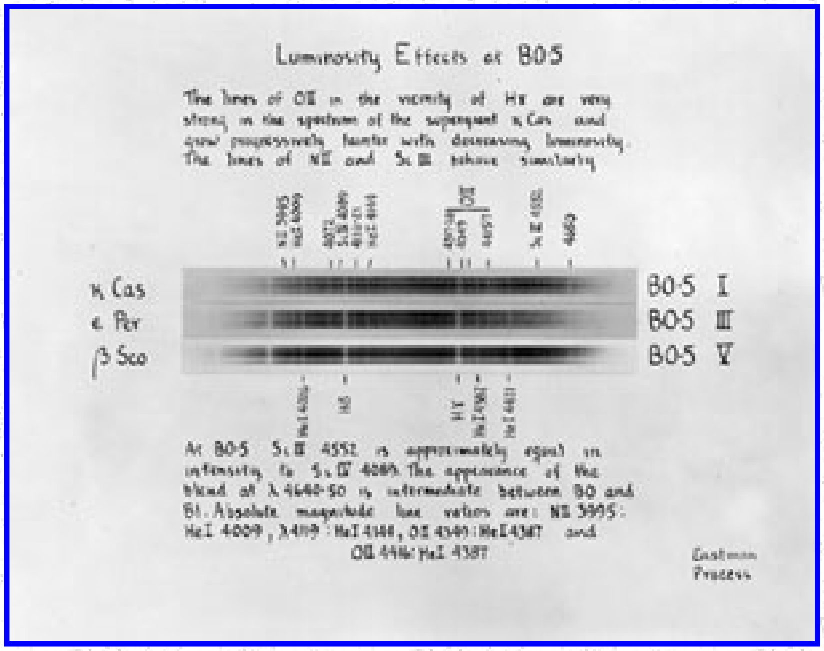
4. B0.5

The blend at λλ 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*γ. 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.

TABLE 4
STANDARDS AT B0.5

Star	MKK	*a*	δ	*m*	HD
κ CAs....	B0.5 I	0:27	+62° 23'	4.2	B0
ε Per......	B0.5 III	3:51	+39 43	3.0	B1
139 Tau..	B0.5 II	5:51	+25 56	4.9	B2
β Sco.....	B0.5 IV	15:59	-19 32	2.9	B1

Plate 9. Luminosity Effects at B0.5



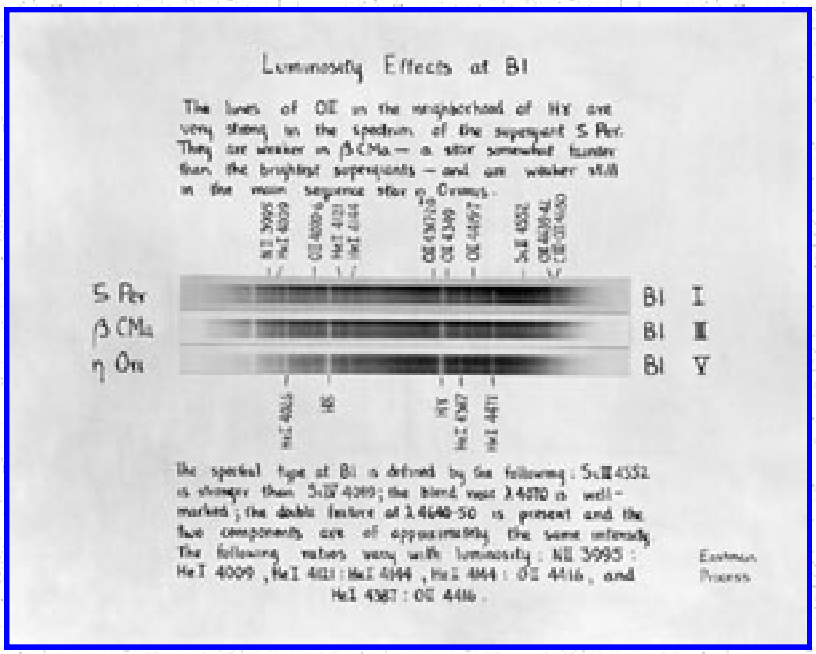
5. B1

The blend at λλ 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 λλ 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.

TABLE 5
STANDARDS AT B1

Star	MKK	*a*	δ	*m*	HD
o Per.....	B1 IV	03:38	+31° 58'	3.9	B1
ζ Per.....	B1 I	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
a 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

Plate 10. Luminosity Effects at B1



Next Contents Previous

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.

NOTES
TABLE 6
STANDARDS AT B2

Star	MKK	*a*	δ	*m*	HD	Notes
γ Peg......	B2.5 IV	0:08	+14°38'	2.9	B2	
ζ Cas.....	B2.5 IV	0:31	+53 21	3.7	B3	
γ Ori......	B2 IV	5:19	+ 6 16	1.7	B2	
χ^2 Ori.....	B2 I	5:58	+20 8	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 2	1.7	B2	
9 Cep......	B2 I	21:35	+61 38	4.9	B2p	2
12 Lac.....	B2 III	22:37	+39 42	5.2	B2	

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 Ori.

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.

Plate 11. Luminosity Effects at B2

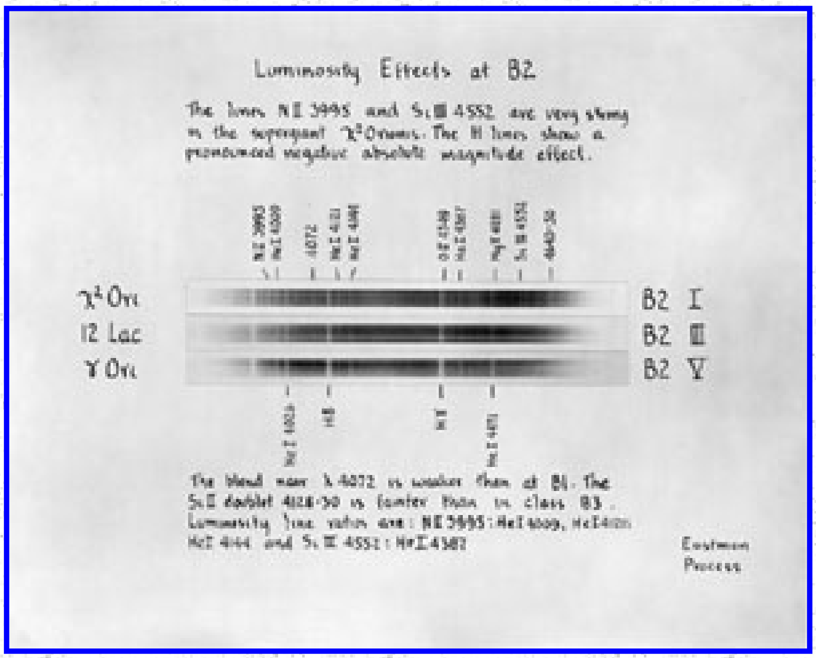


Plate 12. The Be Stars and Phi Persei

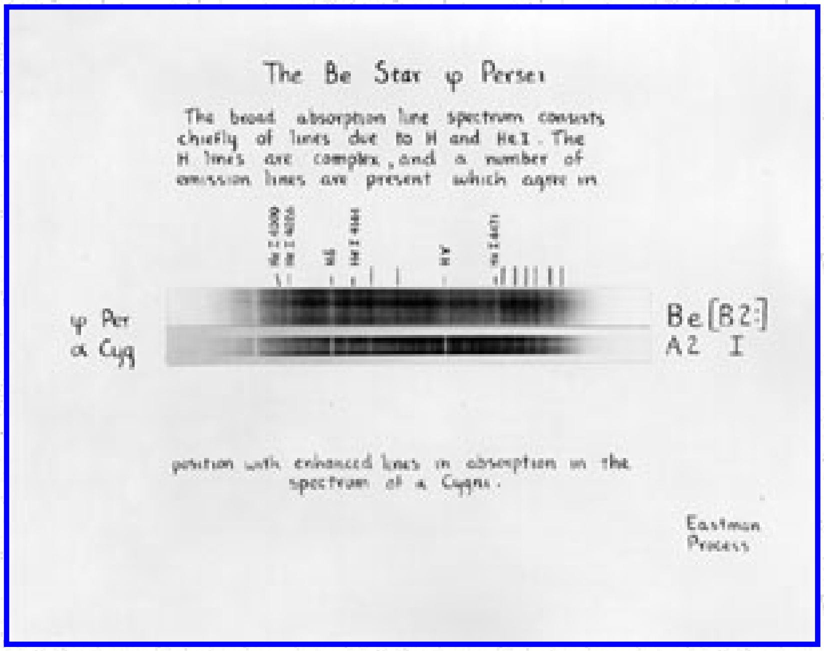


Plate 13. The Bnn Stars

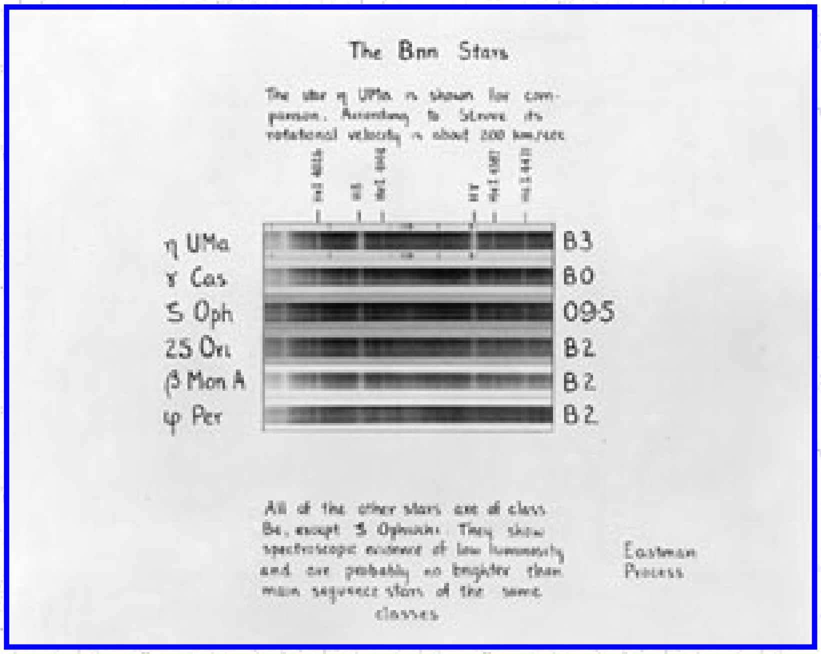
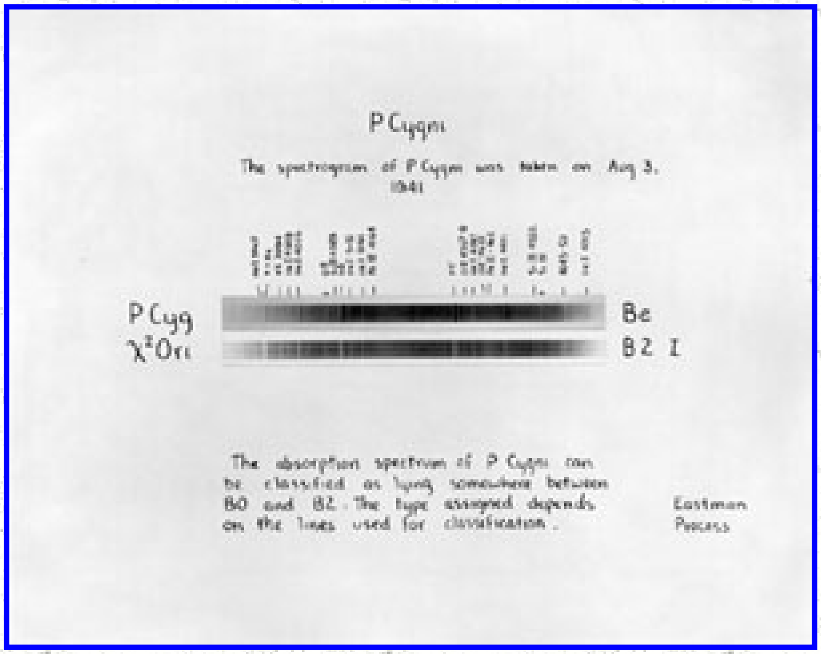


Plate 14. P Cygni



Next Contents Previous

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.

TABLE 7
STANDARDS AT B3

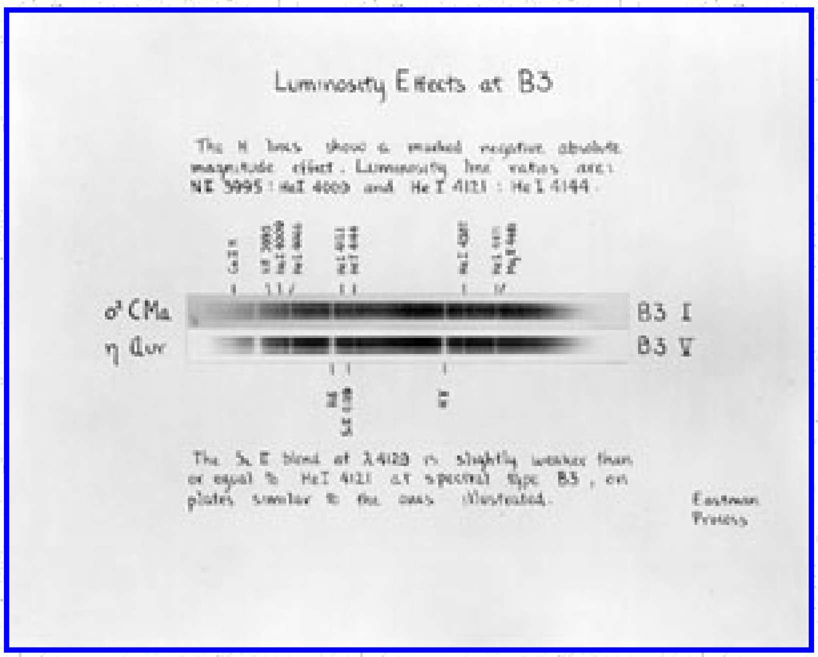
Star	MKK	*a*	δ	*m*	HD	Notes
ϵ Cas.....	B3 III	01:47	+63°11'	3.4	B3	1
η Aur.....	B3 V	04:59	+41 06	3.3	B3	
χ Aur.....	B3 I	05:26	+32 07	4.9	B1	
o^2 CMA...	B3 I	06:58	-23 41	3.1	B5p	
η UMa....	B3 V	13:43	+49 49	1.9	B3	2
ι Her.....	B3 IV	17:36	+46 04	3.8	B3	
σ Sgr.....	B3 IV-V	18:49	-26 25	2.1	B3	
55 Cyg....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

NOTES

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.

Plate 15. Luminosity Effects at B3



Next Contents Previous

Next | Contents | Previous

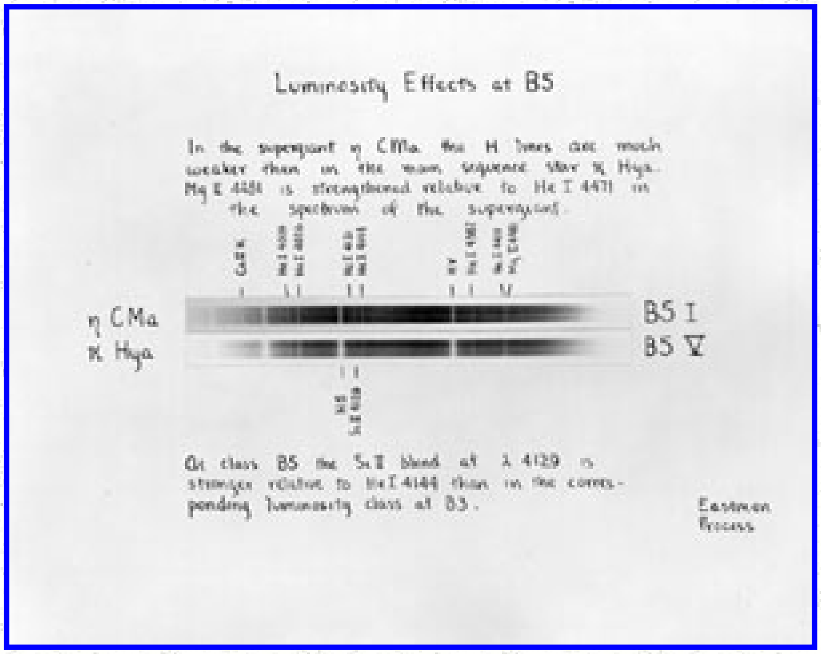
8. B5

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.

TABLE 8
STANDARDS AT B5

Star	MKK	*a*	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

Plate 16. Luminosity Effects at B5



Next | Contents | Previous

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.

TABLE 9
STANDARDS AT B8

Star	MKK	*a*	δ	*m*	HD
β Per......	B8 V	3:01	+40°34'	2.2	B8
η Tau......	B8 III	3:41	+23 48	3.0	B5p
β Ori......	B8 I*a*	5:09	- 8 19	0.3	B8p
β Tau......	B8 III	5:20	+28 31	1.8	B8
β CMi.....	B8 V	7:21	+ 8 29	3.1	B8
a Leo......	B8 V	10:03	+12 27	1.3	B8
β Lib.......	B8 V	15:11	- 9 1	2.7	B8

Plate 17. Luminosity Effects at B8

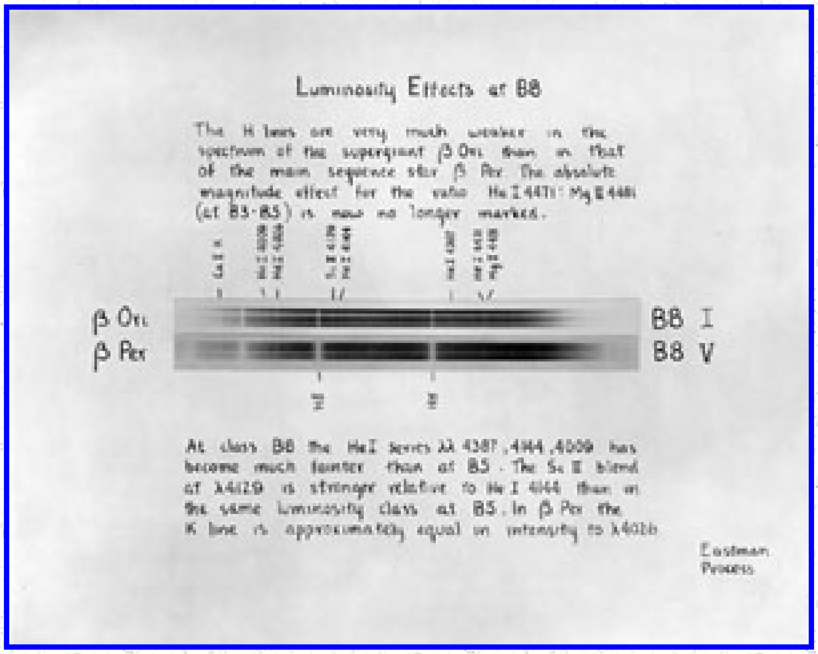
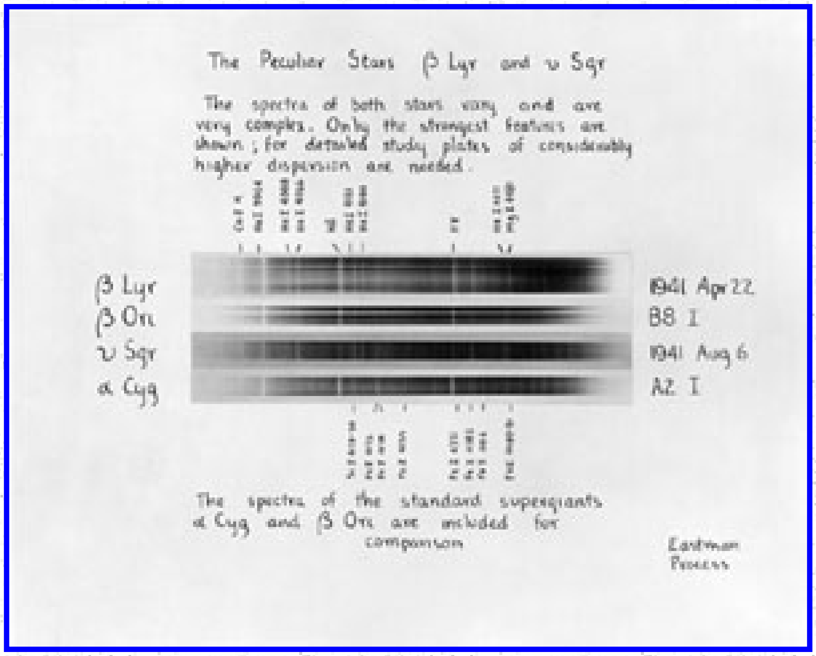


Plate 18. The Peculiar Stars Beta Lyr and Nu Sgr



Next Contents Previous

Next Contents Previous

10. The Spectrum of ζ Draconis

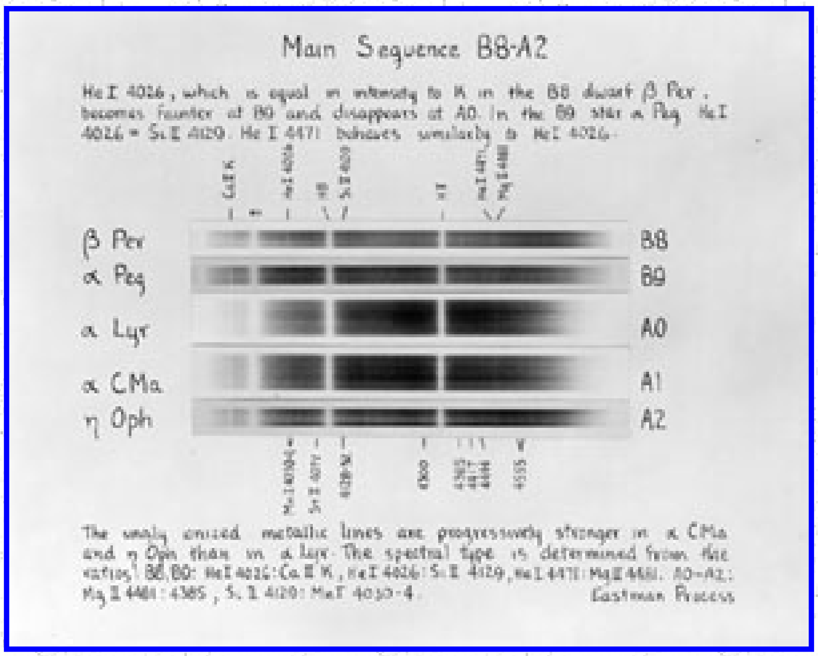
From the lines of *He* I, *Mg* II, and *Si* II the spectral type would be judged to be B8. The Balmer lines are very peculiar; they are weak but do not have the sharp-edged appearance associated with high luminosity. A superficial examination might indicate that the star belongs in luminosity class II at B8. A comparison with the A0 Ib star η Leo shows, however, that the shape of the Balmer lines - in particular H δ and Hε - 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".039 ± 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.

Plate 19. Main Sequence B8 - A2



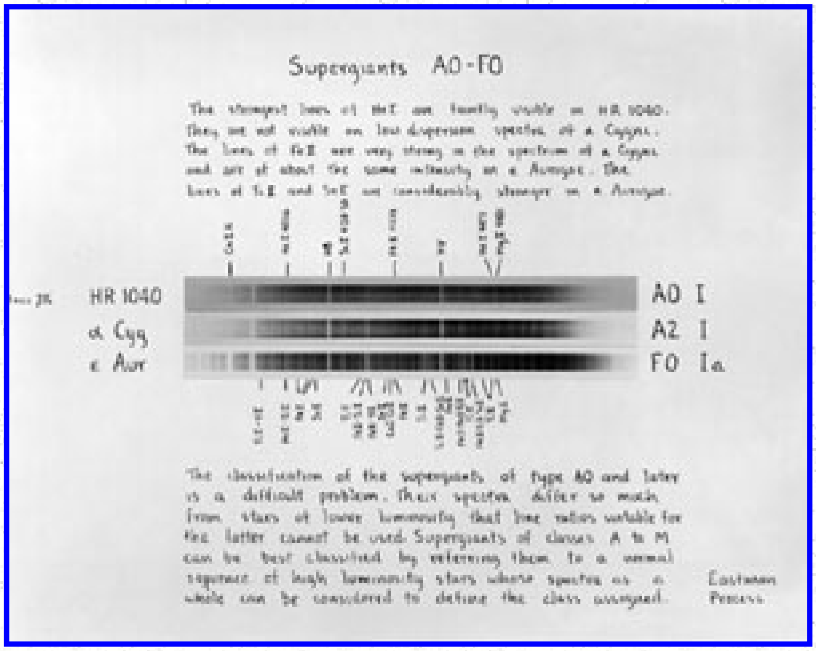
When spectra of very low dispersion are used, the classification seems to be a rather simple matter. If the C-stars and peculiar objects are omitted from consideration, the growth of K with respect to the hydrogen lines from B9 to F0 appears to be smooth and rapid and a sensitive criterion of spectral 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.

Plate 20. Supergiants A0 - F0



Next Contents Previous

12. B9

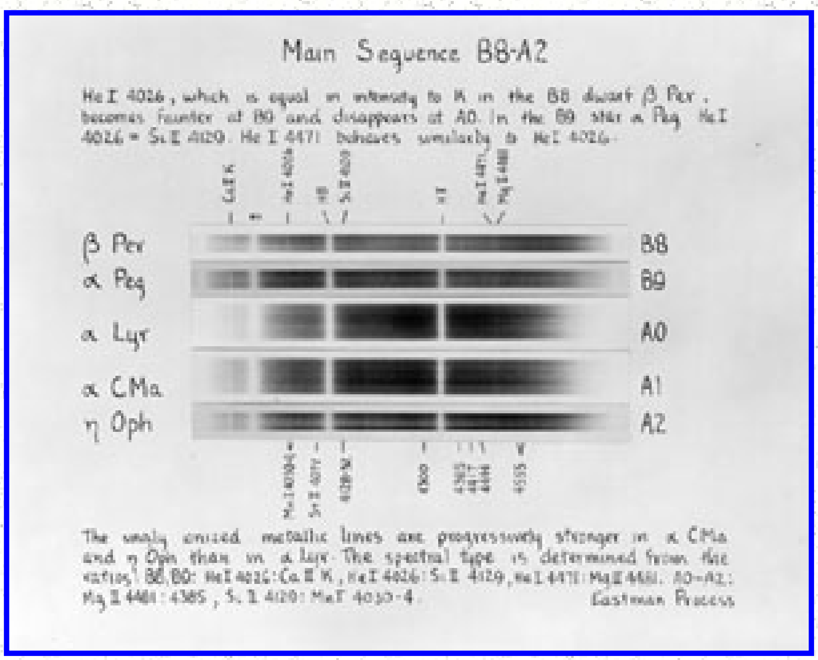
The line *He* I 4026 is weaker relative to K than in class B8. *He* I 4471 is considerably fainter than *Mg* II 4481.

TABLE 10
STANDARDS AT B9

Star	MKK	*a*	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
a Peg......	B9 V	22:59	+14 40	2.6	A0

The luminosity classification is based on the appearance of the wings of the H lines.

Plate 19. Main Sequence B8 - A2



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.

TABLE 11
STANDARDS AT A0

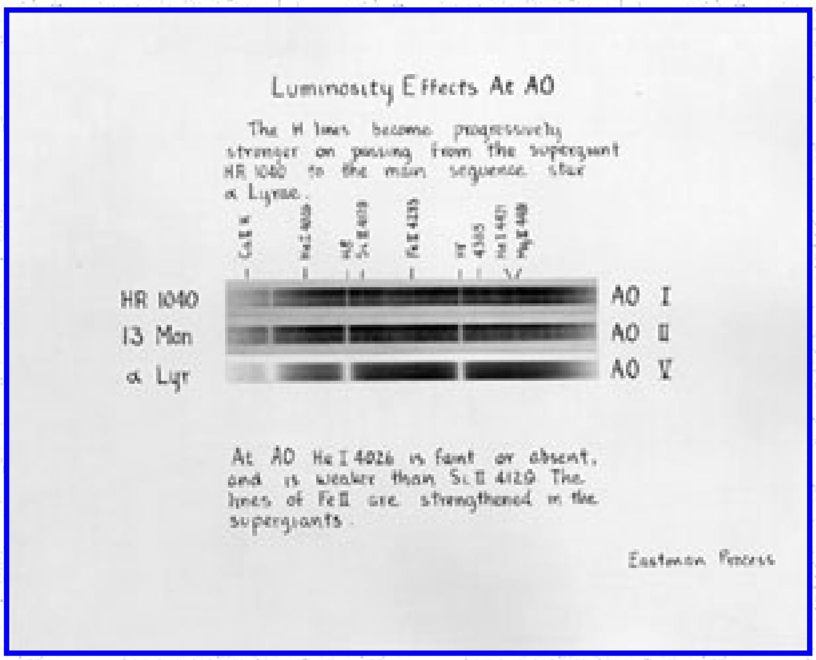
Star	MKK	*a*	δ	*m*	HD	Note
C Hya....	A0 V	08:20	-03°35'	4.0	A0	
γ UMa....	A0 V	11:48	+54 15	2.5	A0	
a CrB....	A0 V	15:30	+27 03	2.3	A0	
a Lyr......	A0 V	18:33	+38 41	0.1	A0	
δ Cyg.....	A0 III	19:41	+44 53	3.0	A0	1

NOTE

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.

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

Plate 21. Luminosity Effects at A0



Next Contents Previous

Next Contents Previous

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.

TABLE 12
STANDARDS AT A1

Star	MKK	*a*	δ	*m*	HD
γ Gem.......	AI V	06:31	+16°29'	1.9	A0
a CMa.......	AI V	06:40	-16 35	-1.6	A0
a Gem A...	AI V	07:28	+32 06	2.0	A0
β UMA.....	AI V	10:55	+56 55	2.4	A0

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

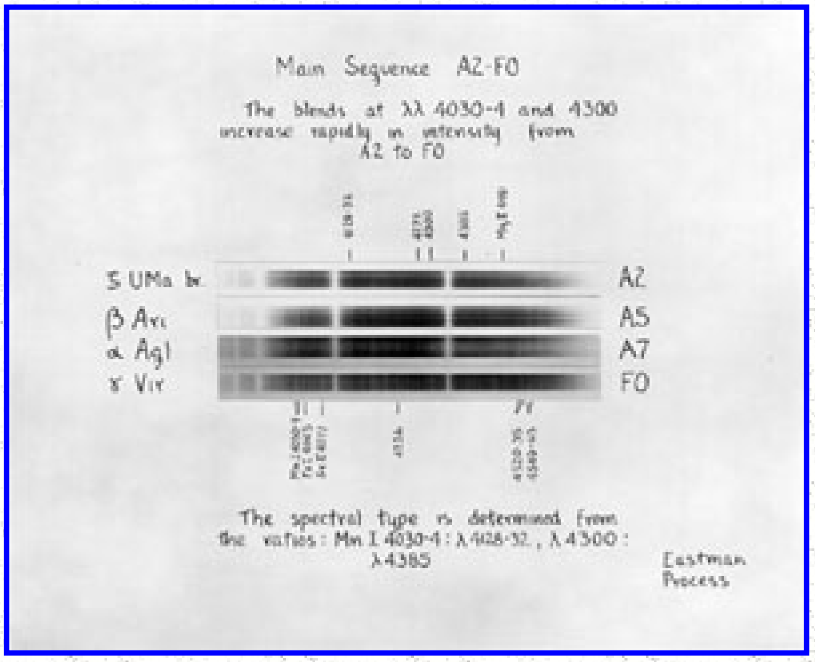
The line at λ 4385 is stronger relative to *Mg* II 4481 than in class A1. The blend at λ 4129 is considerably stronger than *Mn* I 4030-4034.

TABLE 13
STANDARDS AT A2

Star	MKK	*a*	δ	*m*	HD
β Aur.........	A2 IV	05:52	+44°56'	2.1	A0p
λ UMa........	A2 IV	10:11	+43 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

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

Plate 22. Main Sequence A2 - F0



Next Contents Previous

16. A3

The spectral type is determined from the intensity of the blend at λ4032 and the ratio λ4300: λ4385. The luminosity class depends on the ratios λ4416: λ4481, λ4175: λ4032, and λ4226: λ4481, and on the appearance of the wings of the *H* lines.

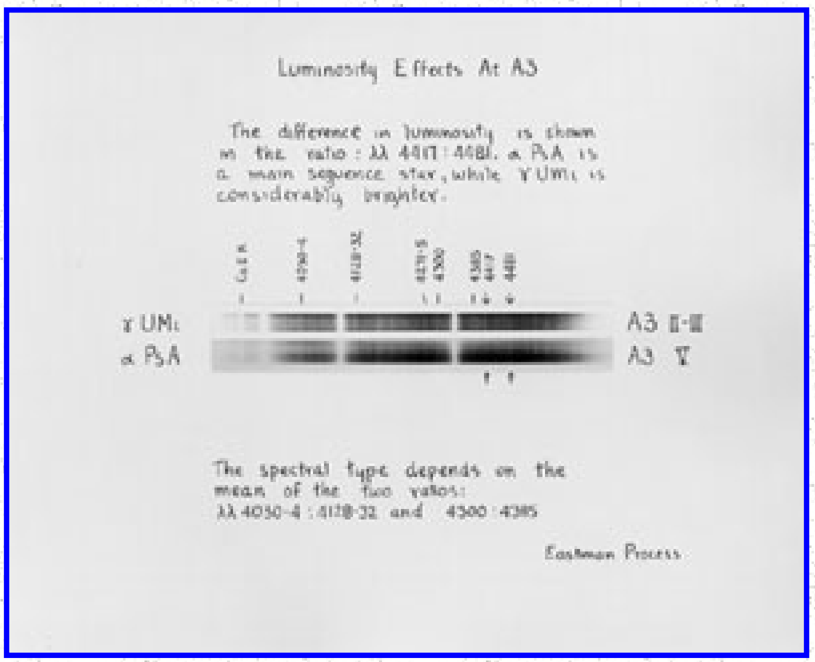
TABLE 14
STANDARDS AT A3

Star	MKK	*a*	δ	*m*	HD	Notes
38 Lyn....	A3 V	09:12	+37°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	13:29	-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
a PsA.....	A3 V	22:52	-30 09	1.3	A3	4

NOTES

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. *a* PsA gives spectroscopic evidence of having the lowest luminosity of any star in the table.

Plate 25. Luminosity Effects at A3



Next Contents Previous

17. A5

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

TABLE 15
STANDARDS AT A5

Star	MKK	*a*	δ	*m*	HD
δ Cas....	A5 V	01:19	+59°43'	3.0	A5
β Ari.....	A5 V	01:49	+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
a Oph.....	A5 III	17:30	+12 38	2.1	A5

Plate 26. Luminosity Effects at A5

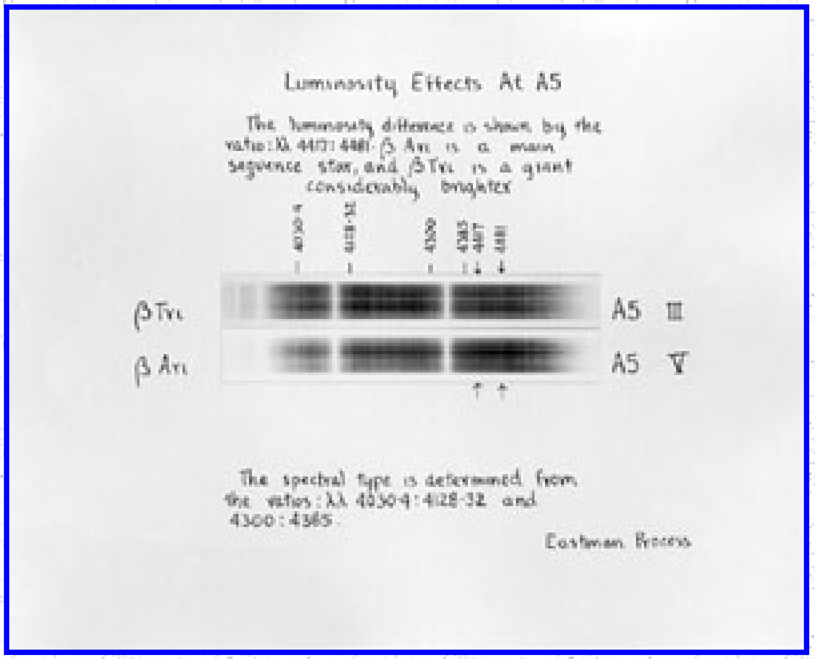
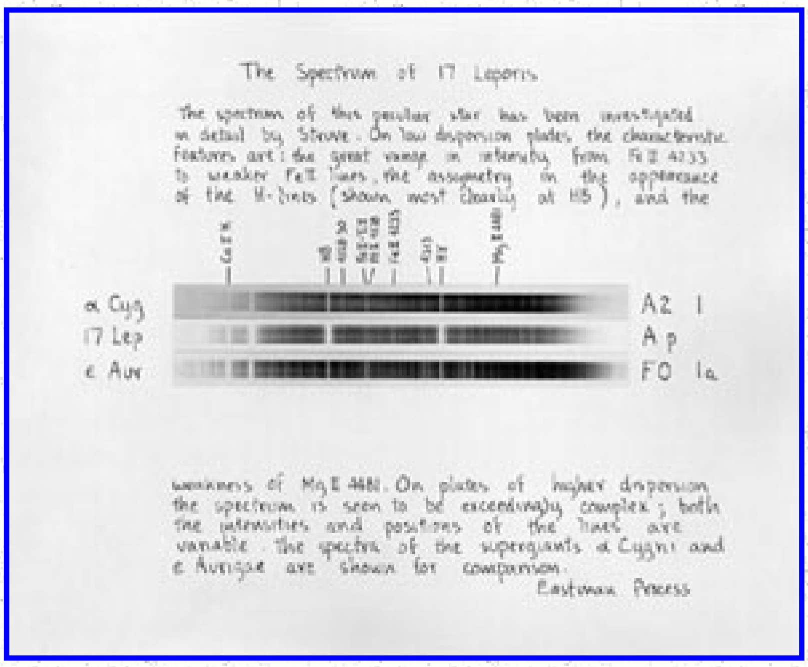


Plate 27. The Spectrum of 17 Leporis



Next Contents Previous

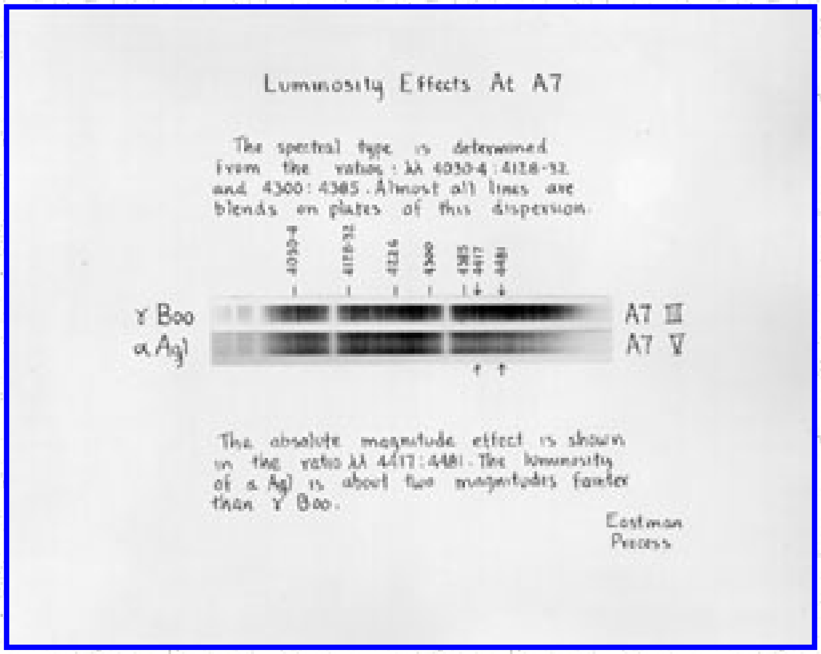
18. A7

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.

TABLE 16
STANDARDS AT A7

Star	MKK	*a*	δ	*m*	HD
γ Boo.....	A7 III	14:28	+38°45'	3.0	F0
a Aql.....	A7 V	19:45	+ 8 36	0.9	A5
a Cep.....	A7 V	21:16	+62 10	2.6	A5

Plate 28. Luminosity Effects at A7



19. F0

The spectral type is determined from the ratio λλ 4030-4034: λλ 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.

TABLE 17
STANDARDS AT F0

Star	MKK	*a*	δ	*m*	HD	Note
ζ Leo....	F0 III	10:11	+23°55'	3.7	F0	
γ Vir.....	F0 V	12:36	-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	

NOTE

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

Plate 29. Main Sequence F0 - M2

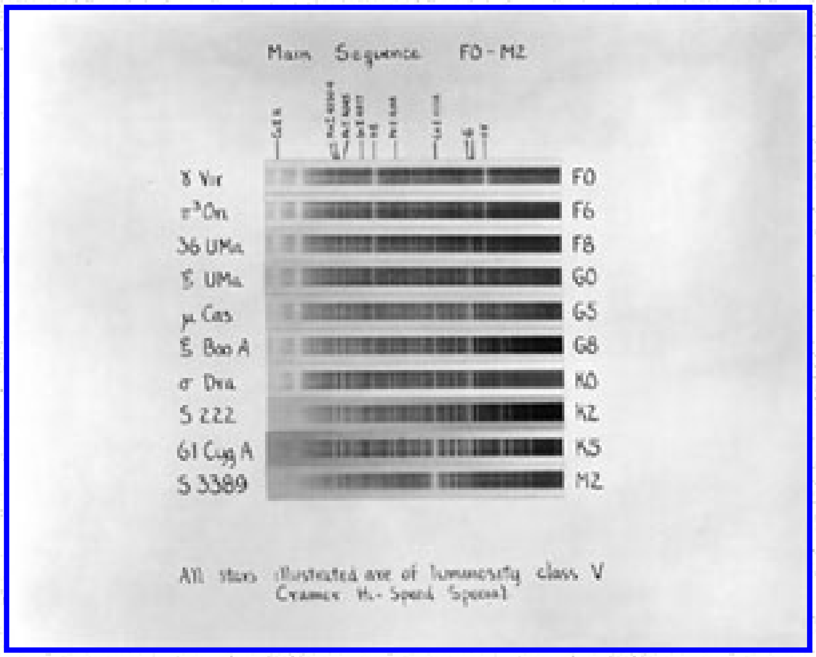


Plate 31. Luminosity Effects at F0

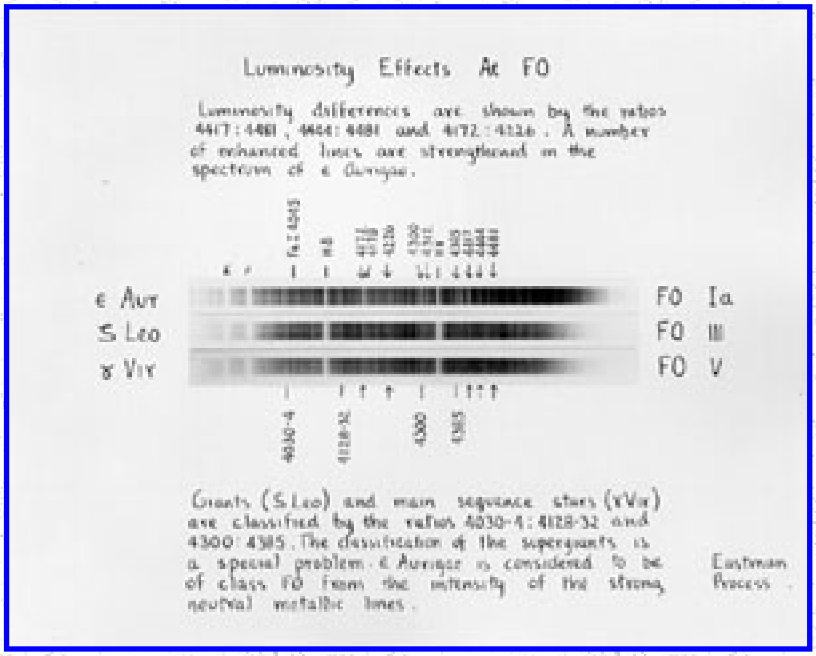
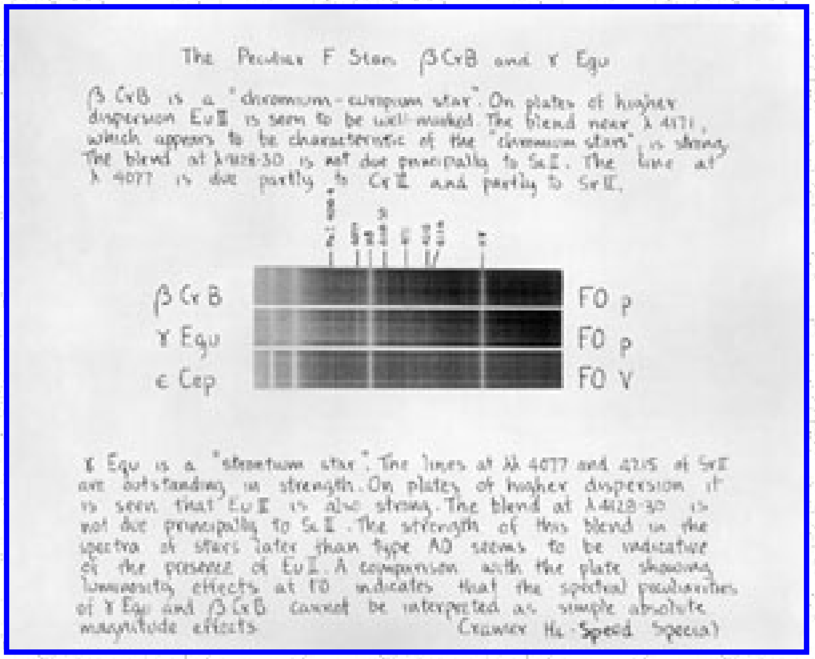


Plate 32. The Peculiar F Stars Beta CrB and Gamma Equ



Next Contents Previous

Next | Contents | Previous

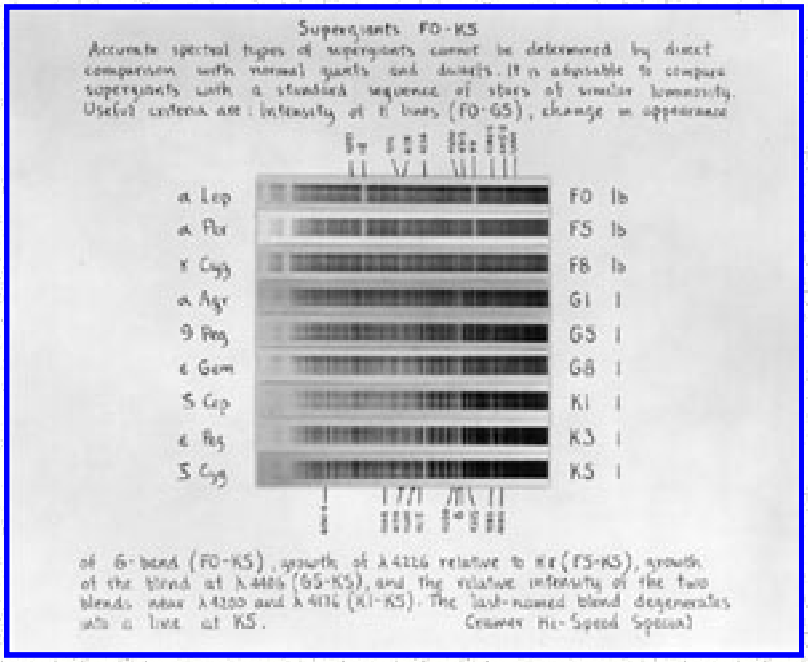
20. F2

The ratio of intensity λλ 4030-4034: λλ 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.

TABLE 18
STANDARDS AT F2

Star	MKK	*a*	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

Plate 30. Supergiants F0 - K5



Next Contents Previous

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.

a And. - B9p. Manganese. The lines of *Mn* II are abnormally strong. On considerably widened, fine-grain spectrograms having a dispersion of 125 A 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.

a 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 4128 - 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 *a* CVn and the spectrum is crowded with metallic lines.

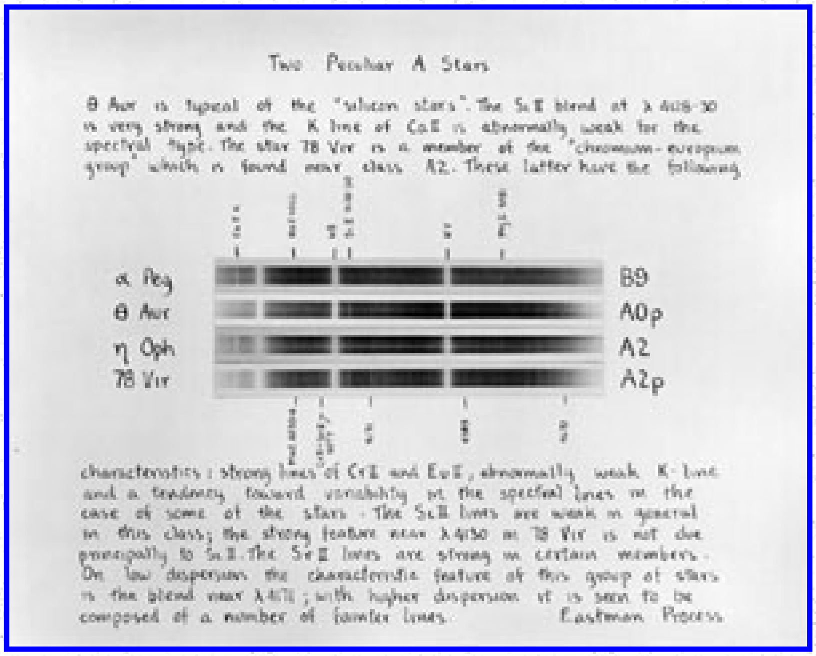
ι *Cas*. - A5p. Strontium.

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 λλ 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 λλ 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.

Plate 24. Two Peculiar A Stars



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.

Next Contents Previous

Next Contents Previous

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.

a 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 a 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.

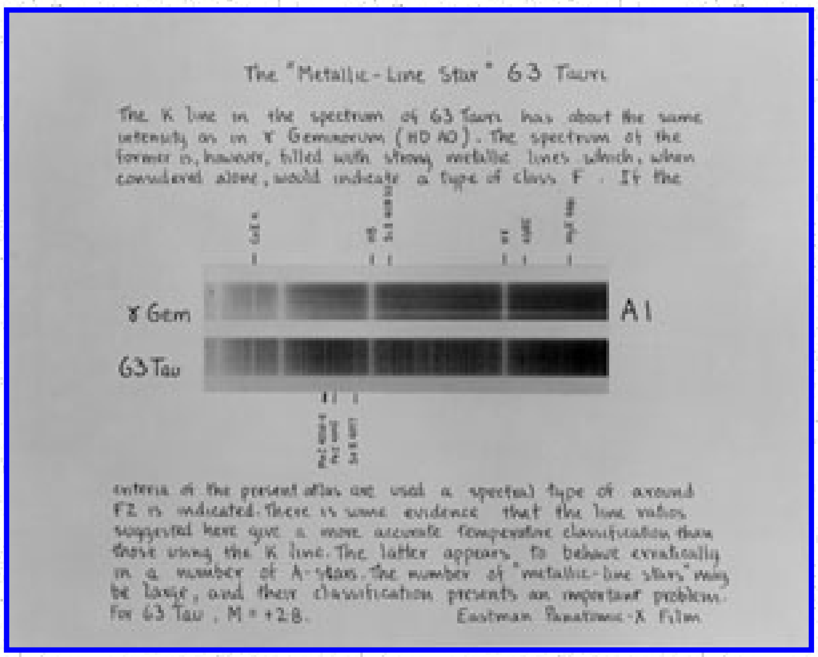
a^2 Lib. - The spectral type from the K line is about A3 and from the metallic lines near A7. The absolute magnitude is probably in the neighborhood of +1.5.

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.

Plate 23. The ``Metallic-Line Star'' 63 Tauri



Next Contents Previous

Next Contents Previous

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.

3. 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.

TABLE 19
STANDARDS AT F5

Star	MKK	*a*	δ	*m*	HD
a Tri.......	F5 III	01:47	+29°06'	3.6	F5
ξ Gem....	F5 III	06:39	+13 00	3.4	F5
a CMi.....	F5 IV	07:34	+05 29	0.5	F5
110 Her...	F5 IV	18:41	+20 27	4.3	F5
β Del.....	F5 III	20:32	+14 15	3.7	F5
ι Peg.....	F5 V	22:02	+24 51	4.0	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.

Plate 30. Supergiants F0 - K5

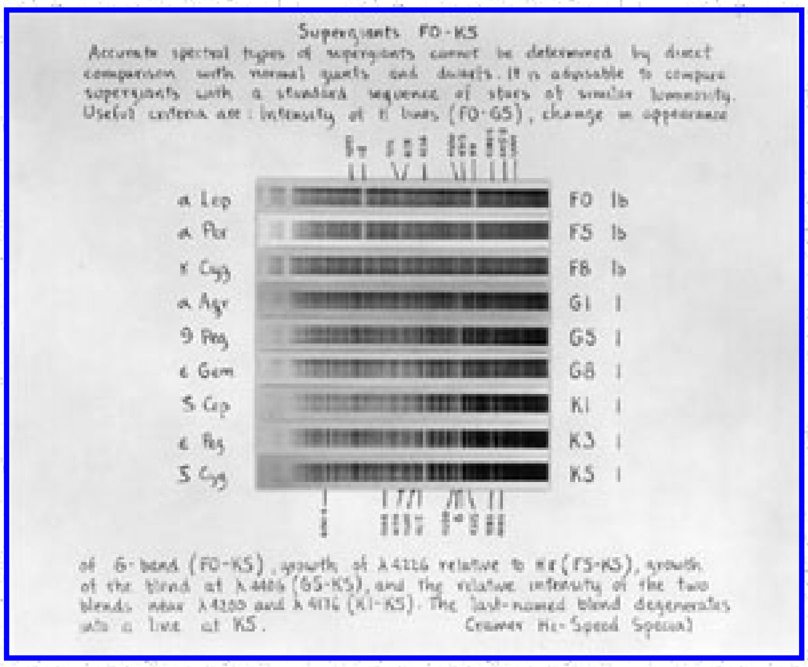
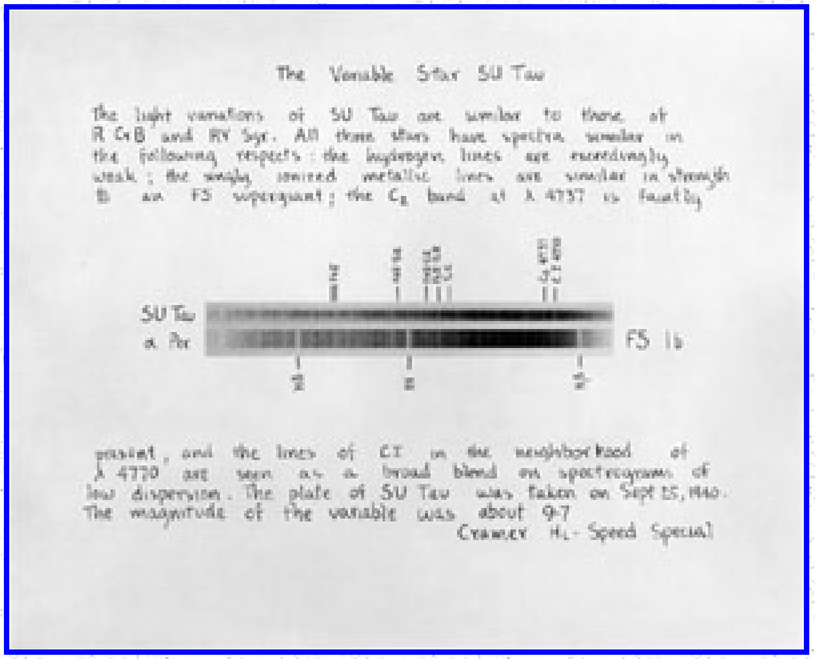


Plate 34. The Variable Star SU Tau



Next Contents Previous

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 λλ 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.

TABLE 20
STANDARDS AT F6

Star	MKK	*a*	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

Plate 33. The Cluster-Type Variable RR Lyrae

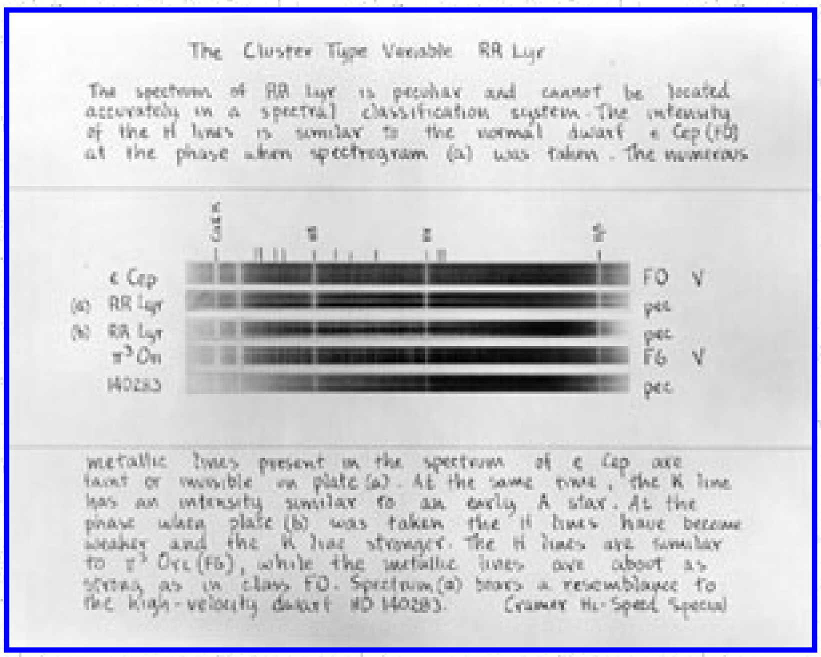
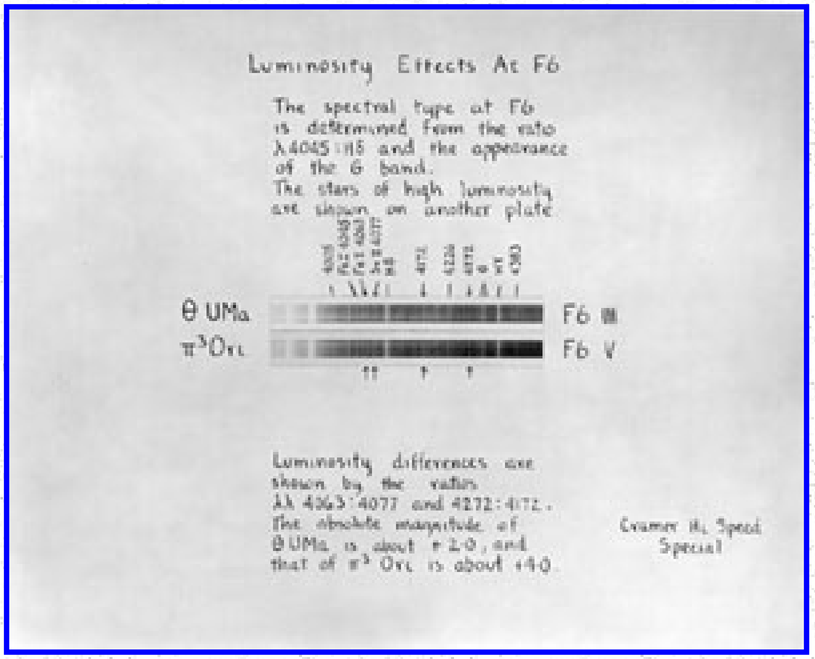


Plate 35. Luminosity Effects at F6



Next Contents Previous

26. F8

The spectral type is determined from the ratios λ 4045: Hδ and λ 4226: Hγ. 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: Hδ and λλ 4171-4173: λ 4226 allow a very accurate luminosity classification to be made.

TABLE 21
STANDARDS AT F8

Star	MKK	*a*	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	23:20	+22 51	4.6	G0

Plate 36. Normal Giants F8 - K5

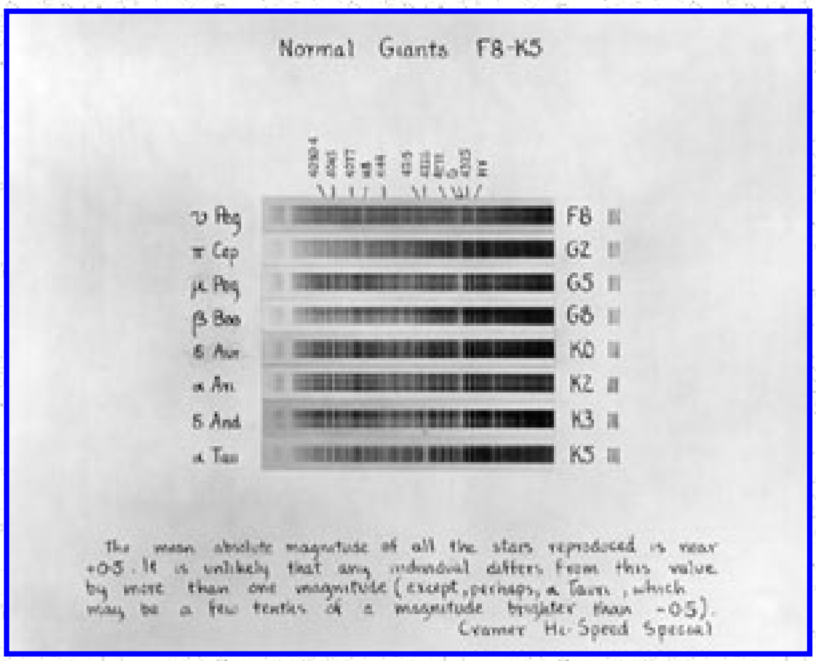


Plate 37. Luminosity Effects at F8

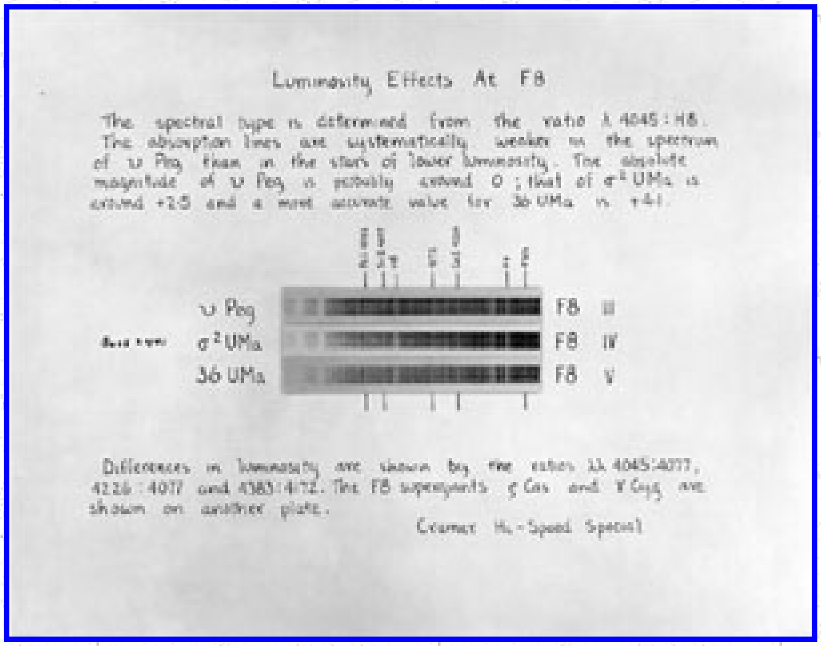
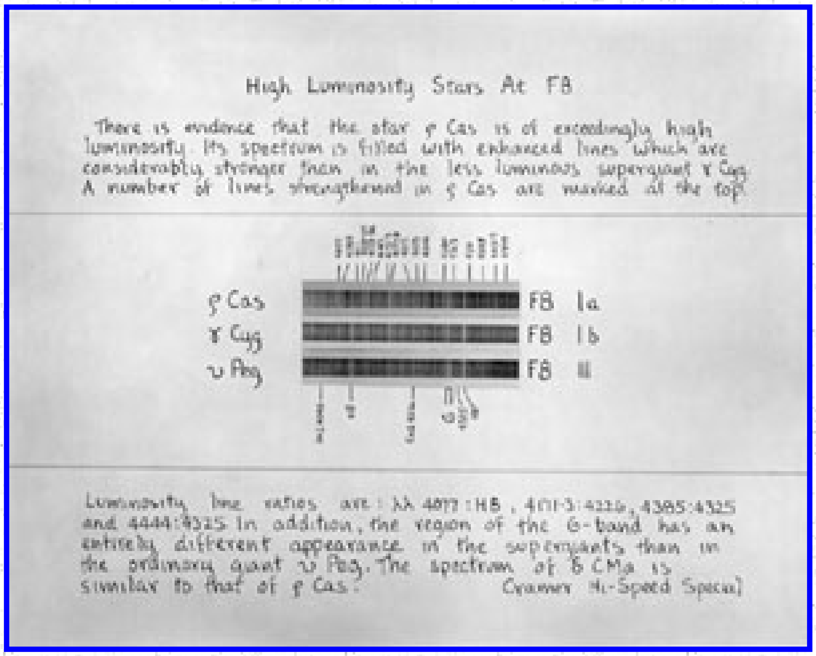


Plate 38. High Luminosity Stars at F8



Next Contents Previous

27. G0

The spectral type is determined from the ratios λ 4045: Hδ and λ 4226: Hγ. 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: Hδ.

TABLE 22
STANDARDS AT G0

Star	MKK	*a*	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	
χ¹ 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	

NOTES

1. The absorption extending toward the violet from λ 4215 is faintly present.
2. Integrated light of system.

Plate 39. The Cepheid Variable X Cygni

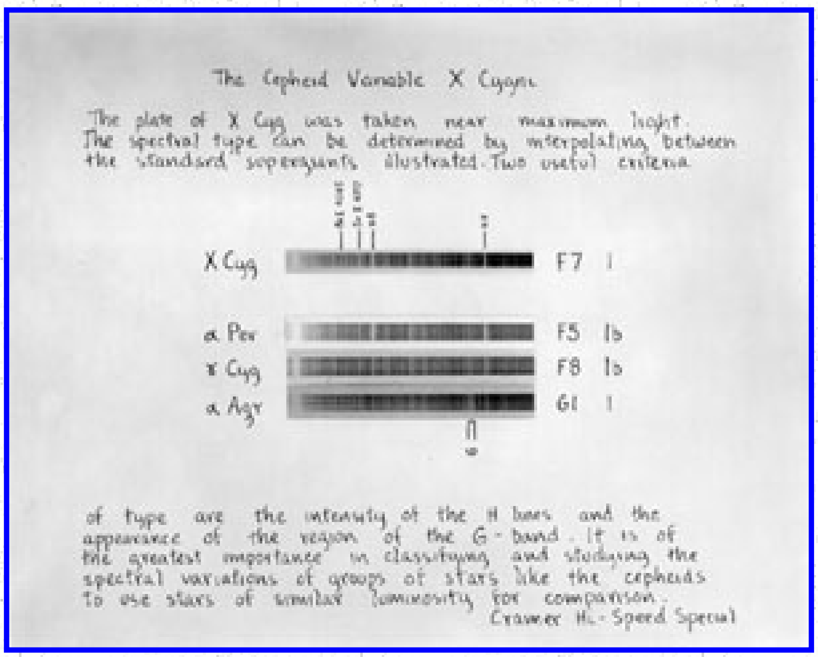
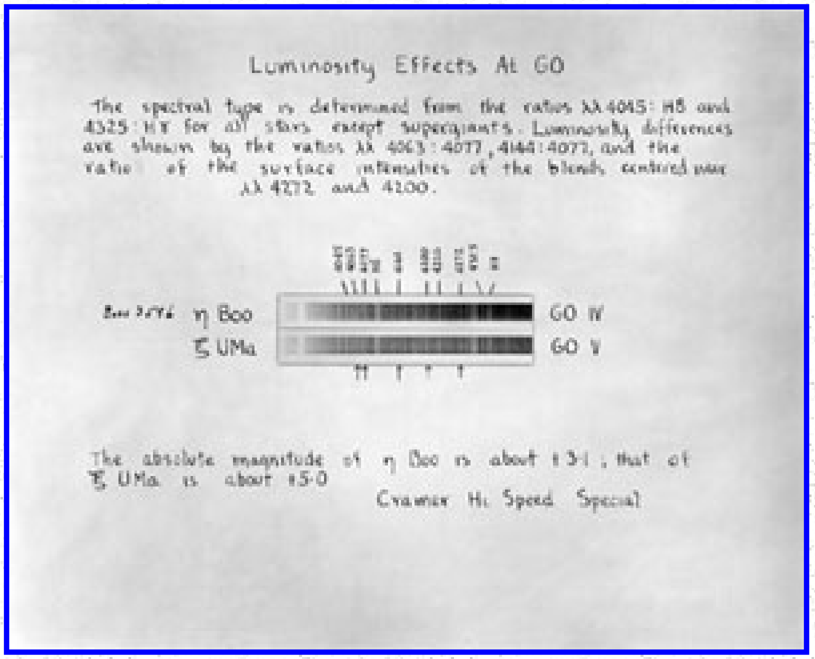


Plate 40. Luminosity Effects at G0



Next Contents Previous

Next Contents Previous

28. G2

The spectral type is determined by the ratios λ 4045: Hδ and λ 4226: Hγ. Luminosity line ratios are λ 4077: λ 4226 and λ 4077: λ 4045.

TABLE 23
STANDARDS AT G2

Star	MKK	*a*	δ	*m*	HD
λ Aur....	G2 IV-V	05:12	+40°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

29. G5

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

TABLE 24
STANDARDS AT G5

Star	MKK	*a*	δ	*m*	HD	Notes
μ Cas....	G5 V	01:01	+54°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	+39 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	

NOTES

1. Considerably fainter spectroscopically than other dwarfs in table.
2. The star appears to be definitely less luminous than μ Her.

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.

Plate 41. Luminosity Effects at G5

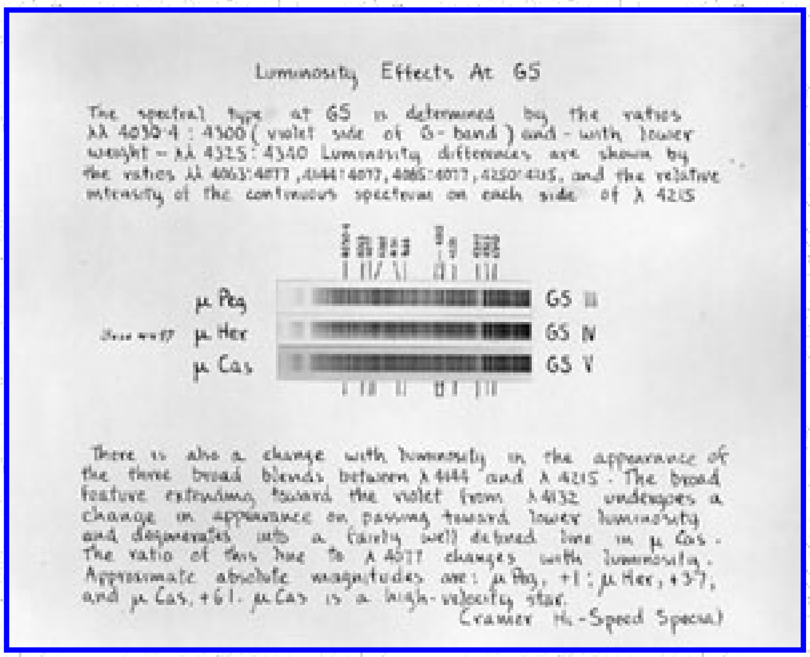


Plate 42. The High-Velocity Star Boss 2527

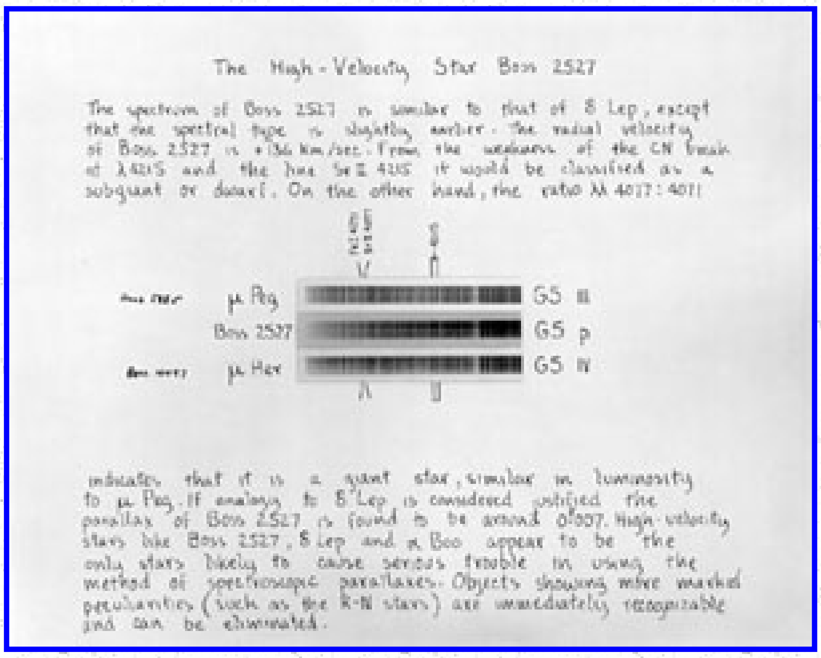
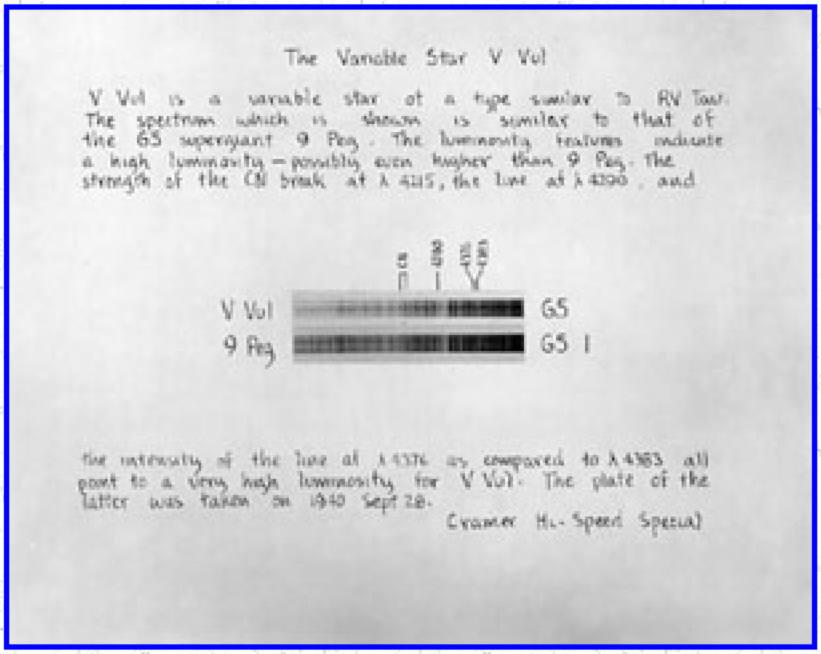


Plate 43. The Variable Star V Vul



Next Contents Previous

30. G8

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

TABLE 25
STANDARDS AT G8

Star	MKK	*a*	δ	*m*	HD	Note
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	
a 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	+29 49	3.4	K0	
μ Peg ...	G8 III	22:45	+24 04	3.7	K0	
λ And ...	G8 III-IV	23:32	+45 55	4.0	K0	

NOTE

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 almost invisible, as in class IV-V.

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.

Plate 44. Luminosity Effects at G8

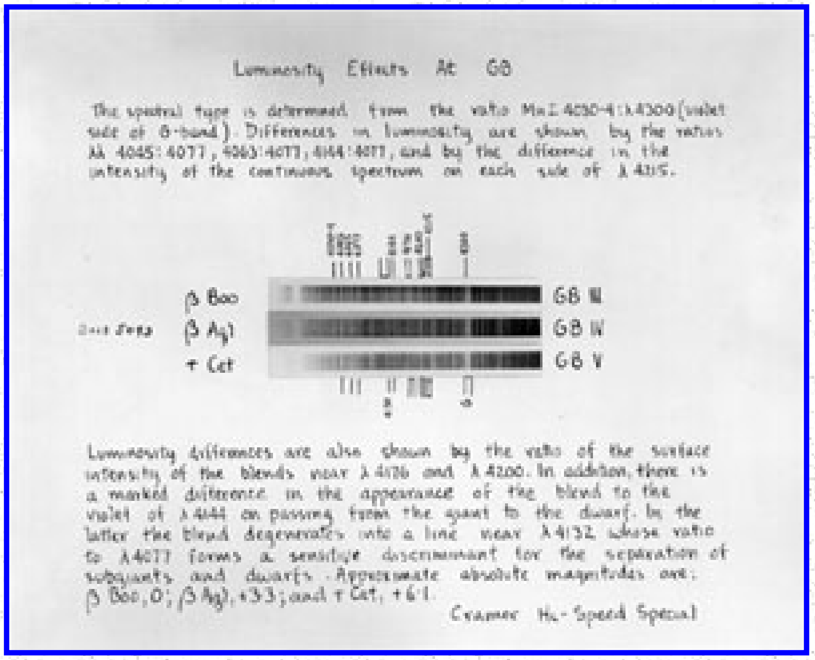
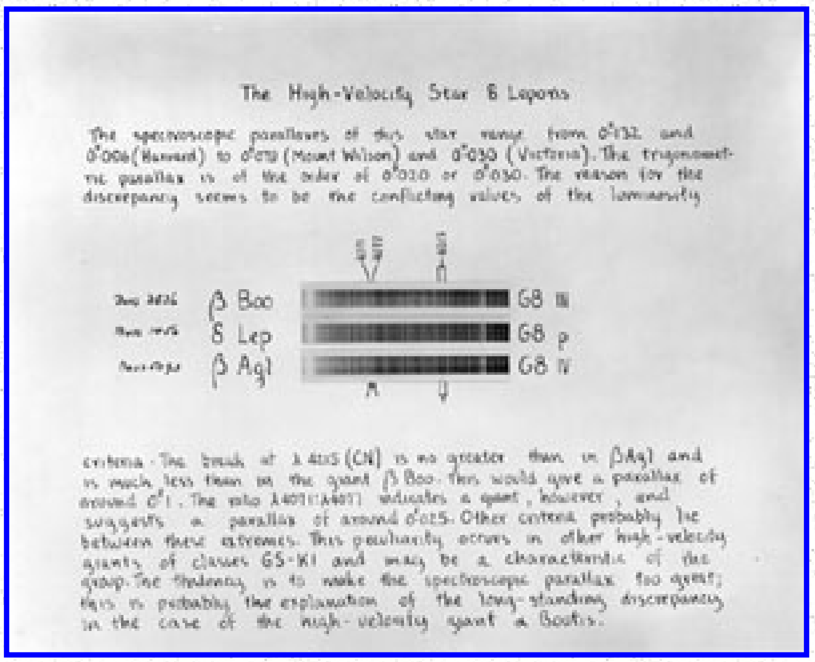


Plate 45. The High-Velocity Star Delta Leporis



Next Contents Previous

31. K0

Spectral type is determined from the ratios λλ 4030-4034: λ 4300, λ 4290: λ 4300, and Hδ: 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.

TABLE 26
STANDARDS AT K0 AND K1

Star	MKK	*a*	δ	*m*	HD	Notes
54 Psc	K0 V	00:34	+20°43'	6.1	K0	
a 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 4	3.4	K0	

NOTES

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 γLeo is a high-velocity system, and the spectral peculiarities are similar to those of the high-velocity stars *a* Boo and δ Lep.

Plate 46. Luminosity Effects at K0

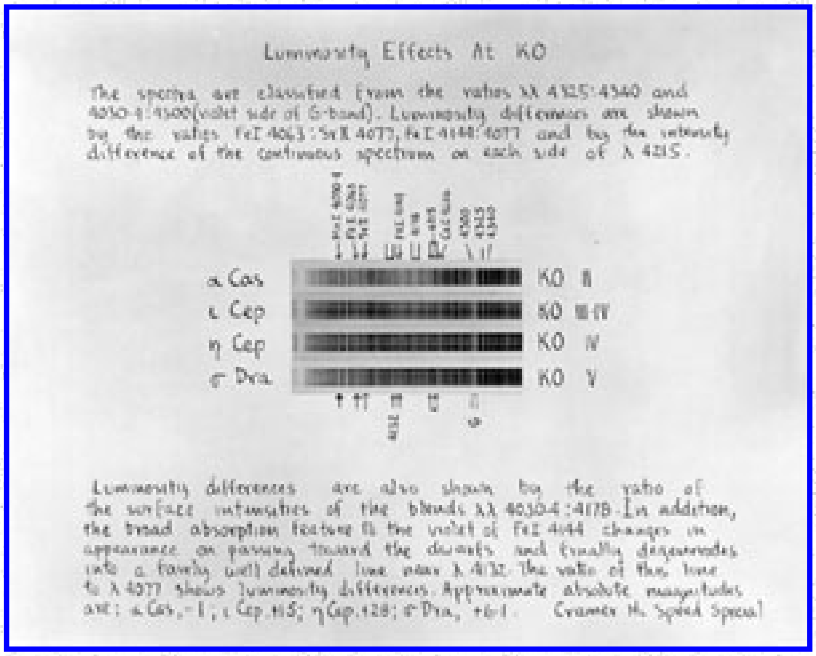
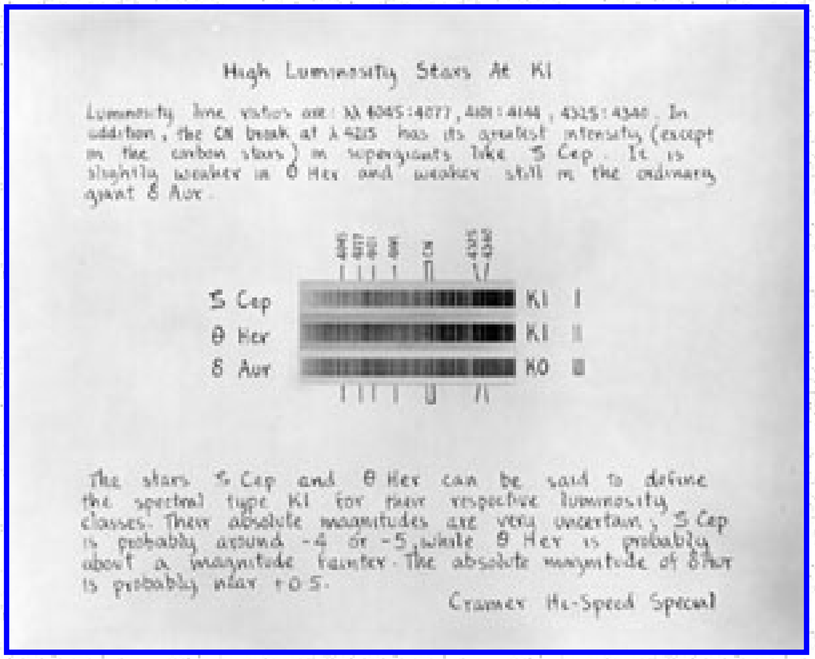


Plate 47. High Luminosity Stars at K1



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.

TABLE 27
STANDARDS AT K2

Star	MKK	*a*	δ	*m*	HD	Note
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 Crv	K2 III	12:05	-22 04	3.2	K0	
a Boo	K2 pec	14:11	+19 42	0.2	K0	1
ι Dra	K2 III	15:22	+59 19	3.5	K0	
a Ser	K2 III-IV	15:39	+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	

NOTE

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. *a* 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.

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.

TABLE 28
STANDARDS AT K3

Star	MKK	*a*	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
a 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
a 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

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

Plate 48. Luminosity Effects at K3

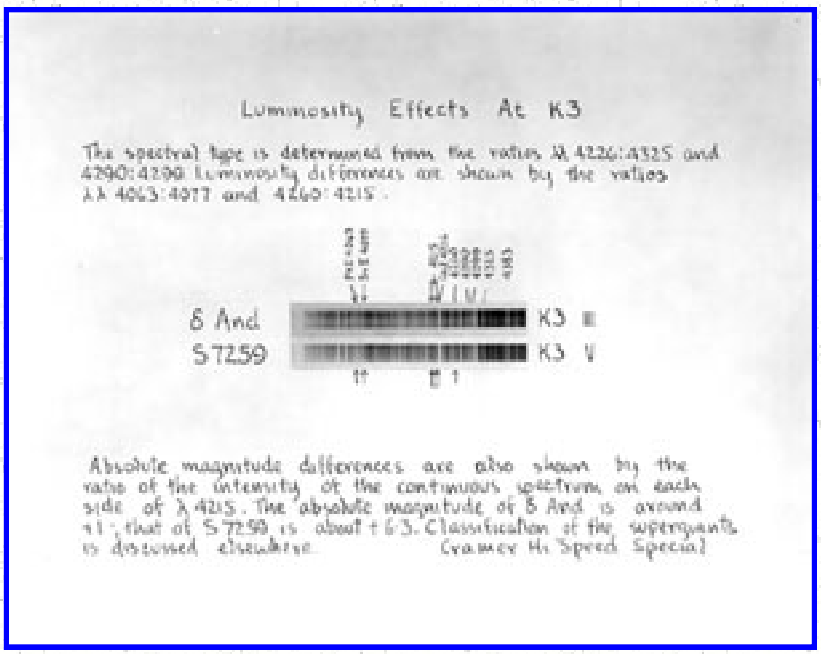
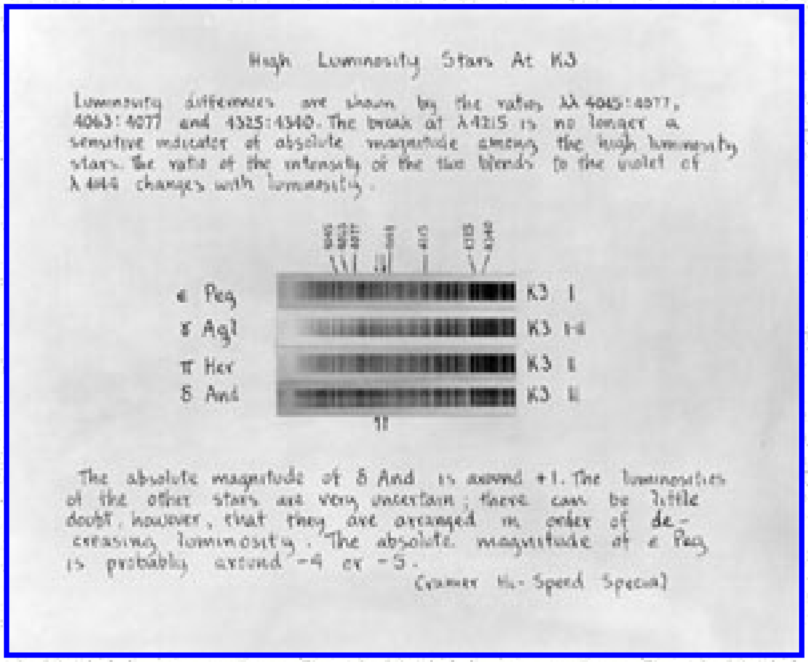


Plate 49. High Luminosity Stars at K3



Next Contents Previous

Next Contents Previous

34. K5

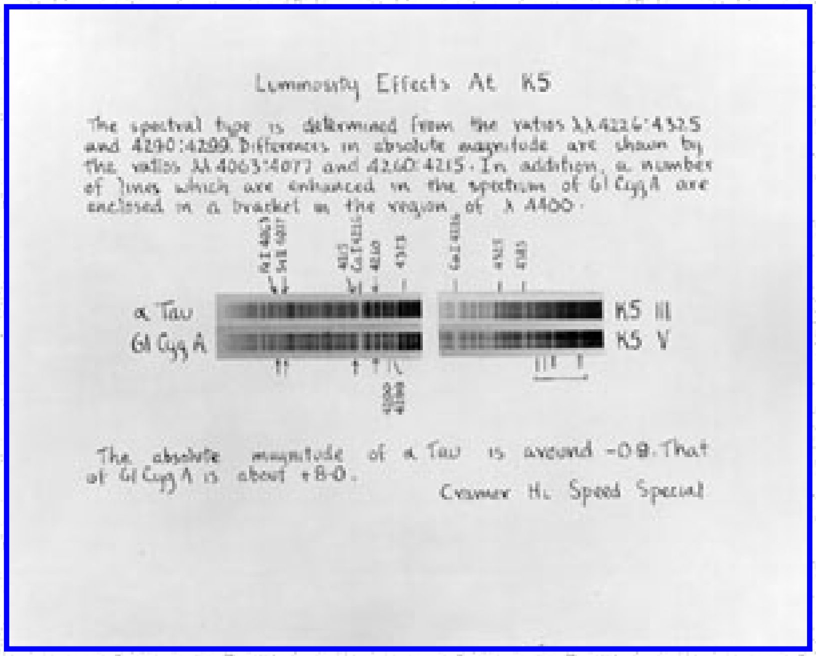
The spectral type is determined from the ratios λ 4226: λ 4325, λ 4290: λ 4299, and λ 4383: λ 4406. Luminosity classes are determined from the ratios λ 4063: λ 4077 and λ 4260: λ 4215.

TABLE 29
STANDARDS AT K5

Star	MKK	*a*	δ	*m*	HD
a 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

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

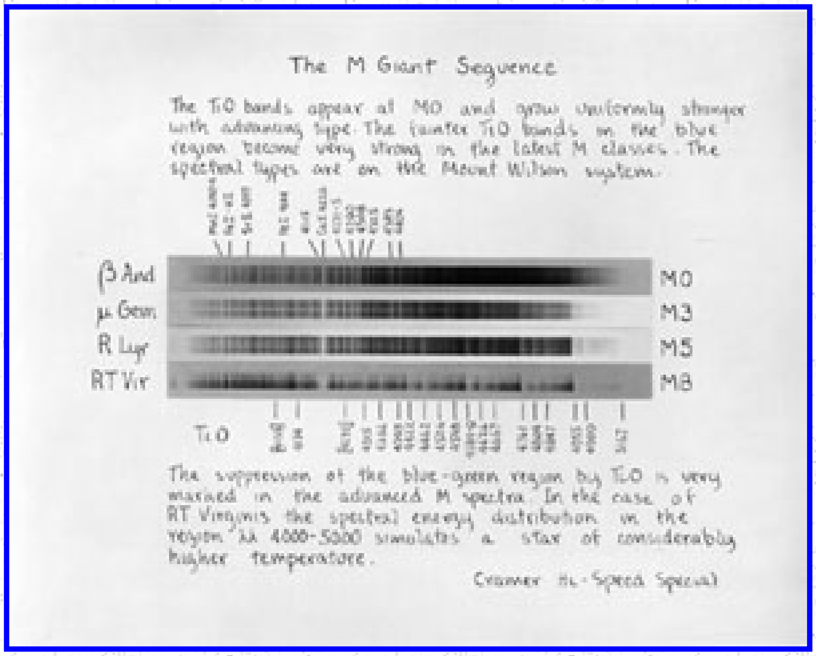
Plate 50. Luminosity Effects at K5



35. The M Stars

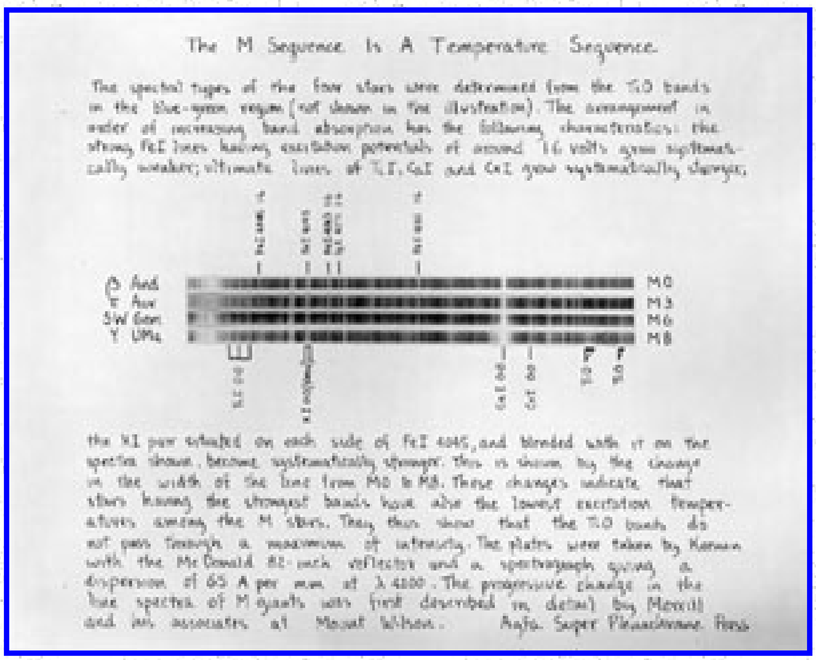
Discussion of the M dwarfs is outside the range of the present *Atlas*. Since no stars have been observed intermediate between M dwarfs and giants, the latter can be considered separately.

Plate 51. The M Giant Sequence



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.

Plate 52. The M Sequence as a Temperature Sequence



The absolute magnitudes of some of the giant M stars have been discussed recently by Keenan, (1) 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.

TABLE 30
STANDARD M GIANTS

Star	MKK	*a*	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	
a Ori	M2 Ib	05:49	+07 23	0.9*	Ma	
a 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

NOTES

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

* Light variable.

Plate 54. A Carbon Star and a Long Period Variable

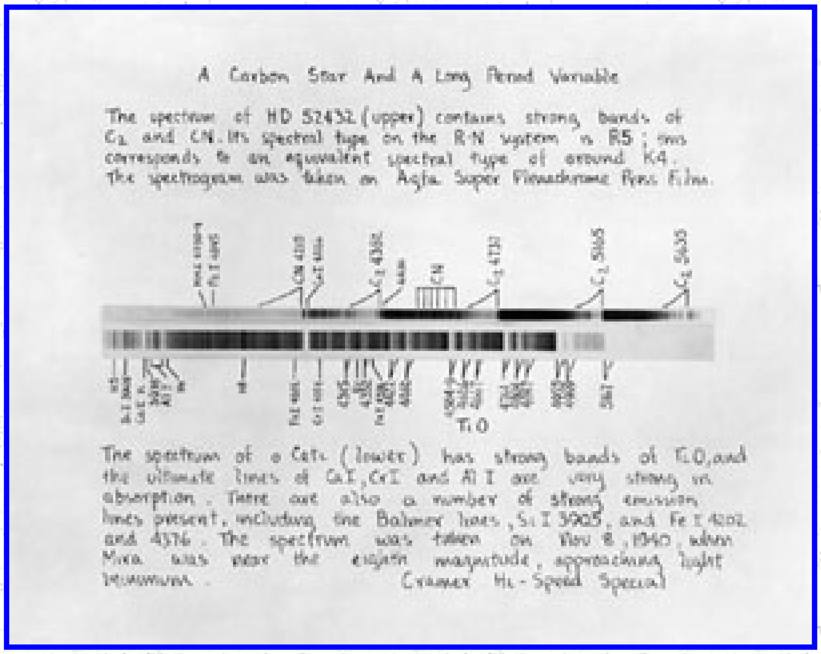
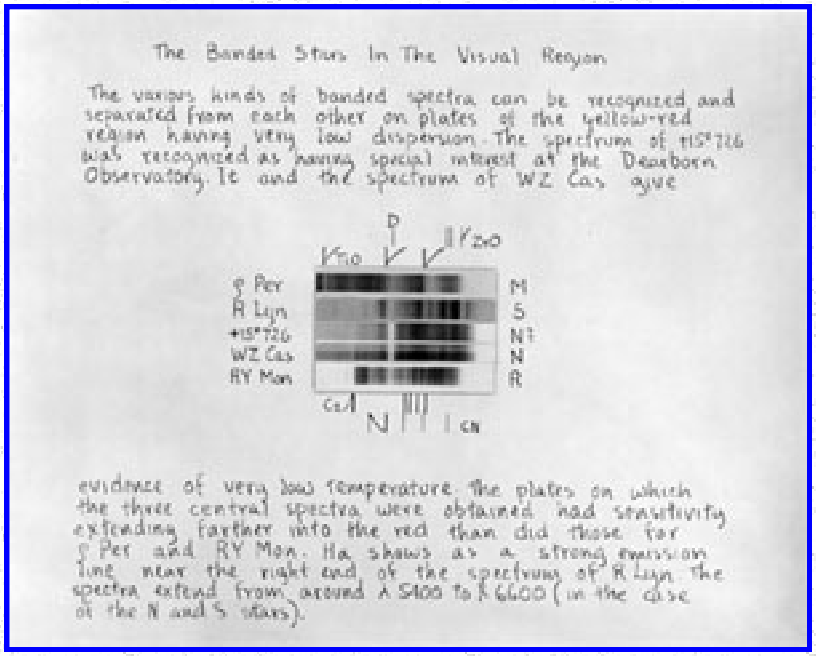


Plate 55. The Banded Stars in the Visual Region



The Banded Stars In The Visual Region

The various kinds of banded spectra can be recognized and separated from each other on plates of the yellow-red region having very low dispersion. The spectrum of +15°726 was recognized as having special interest at the Dearborn Observatory. It and the spectrum of WZ Cas give

evidence of very low temperature. The plates on which the three central spectra were obtained had sensitivity extending farther into the red than did those for ρ Per and RY Mon. Hα shows as a strong emission line near the right end of the spectrum of R Lyn. The spectra extend from around λ 5400 to λ 6600 (in the case of the N and S stars).

---

[1] *Ap. J.*, **95**, 461, 1942. Back.

Next Contents Previous

4. 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 supergiants are: λ4128-λ4130: λ4172-λ4179 (A0-F0), λ4226: Hδ (F5-G5), λ4045: Hλ (F5-G8), λ4226: Hλ (F5-K5), λ4325: Hλ (F5-G2), blend at λ4176: blend at λ4200 (G5-K5), λ4383: λ4406 (G8-K5), and the appearance of the region of the G band (F0-K5).

Plate 4. Supergiants O9.5 - A0

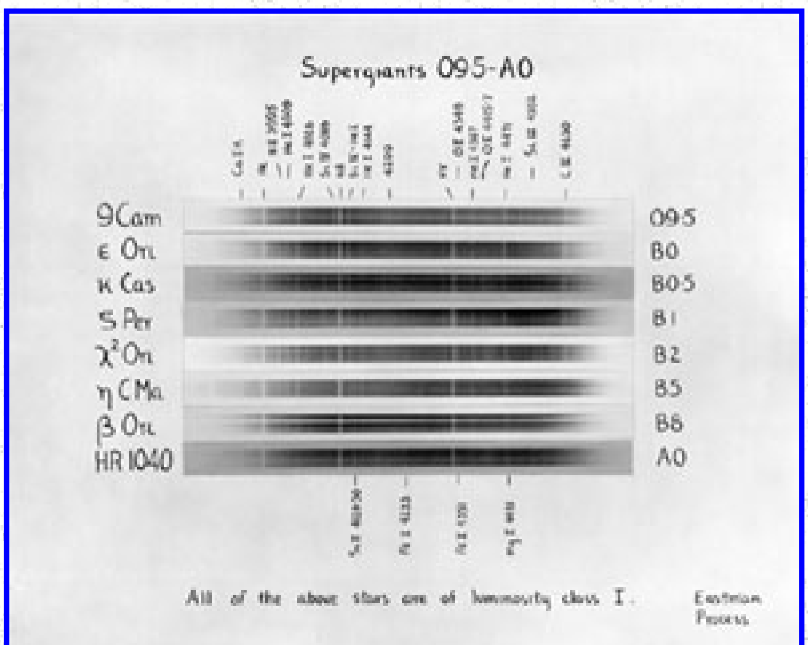


Plate 20. Supergiants A0 - F0

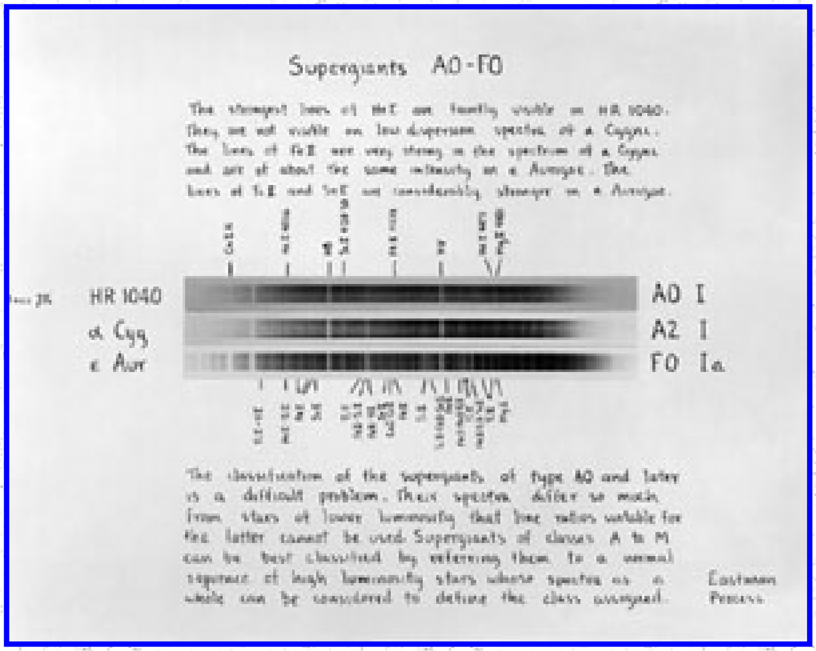


Plate 30. Supergiants F0 - K5

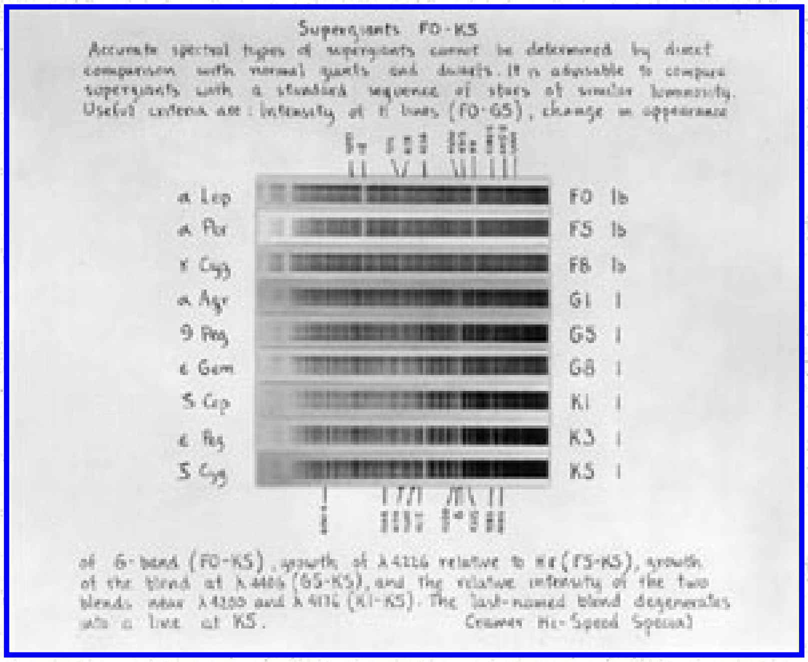


Plate 38. High Luminosity Stars at F8

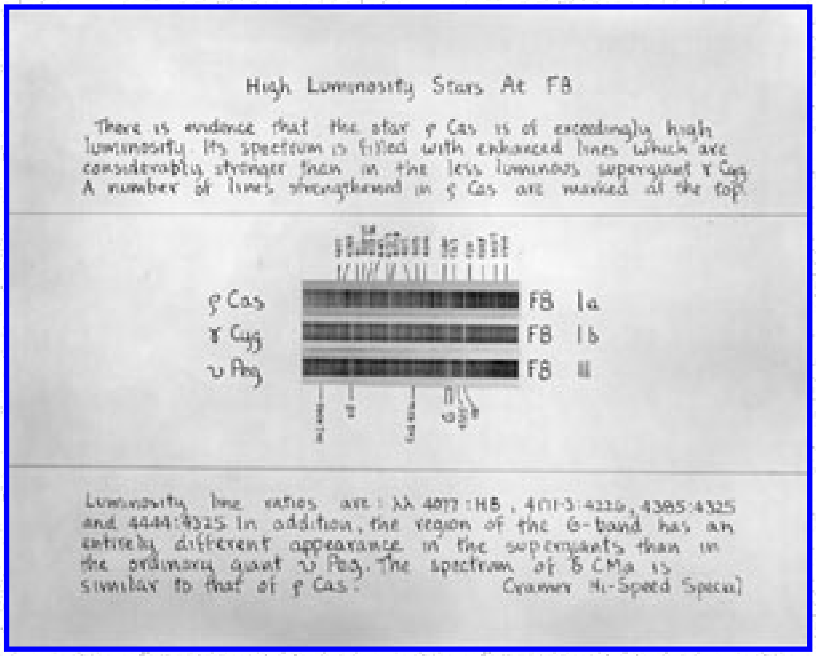


Plate 47. High Luminosity Stars at K1

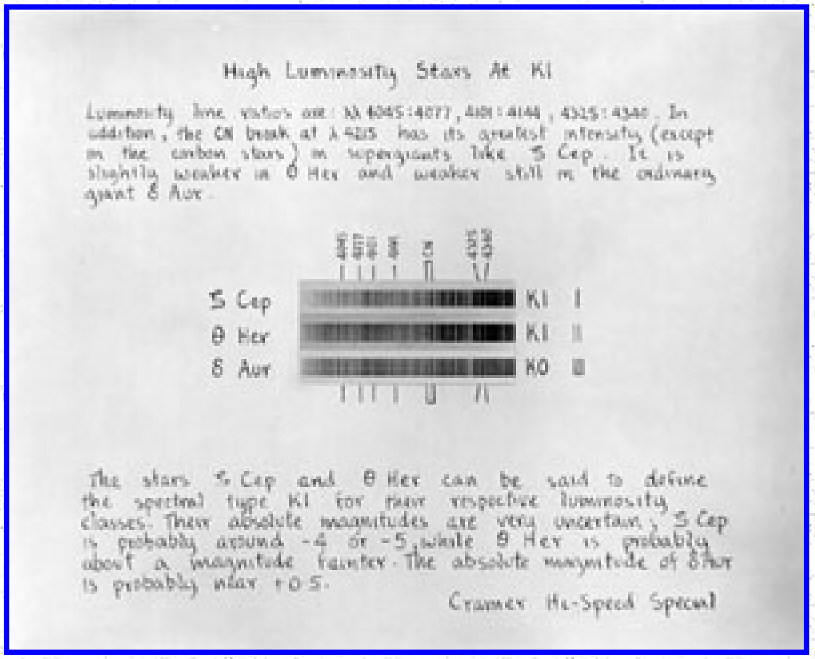


Plate 49. High Luminosity Stars at K3

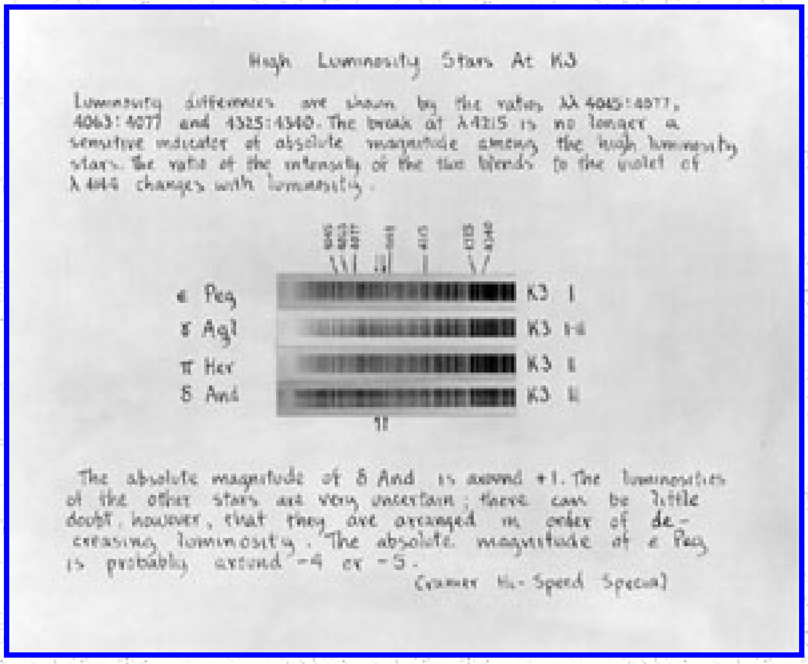
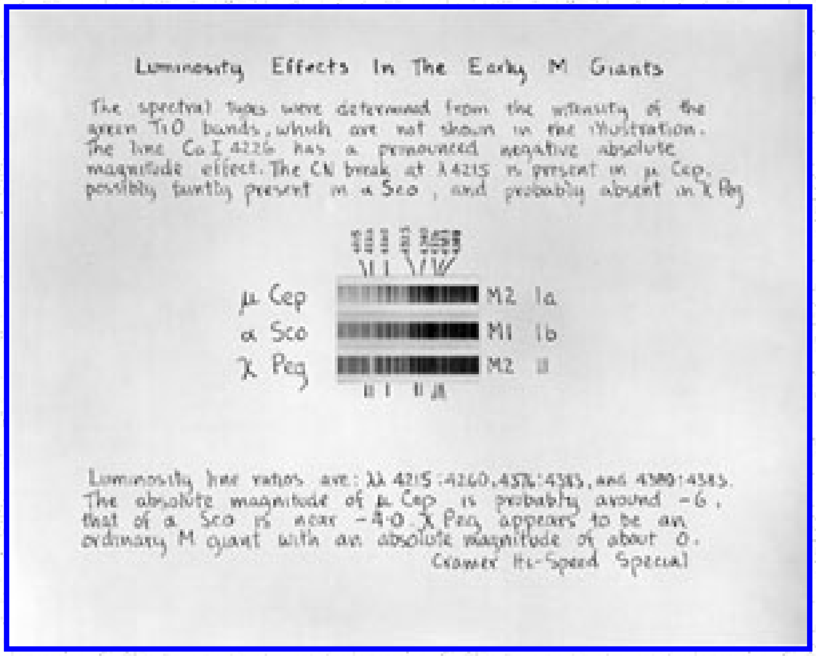


Plate 53. Luminosity Effects in the Early M Giants



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.

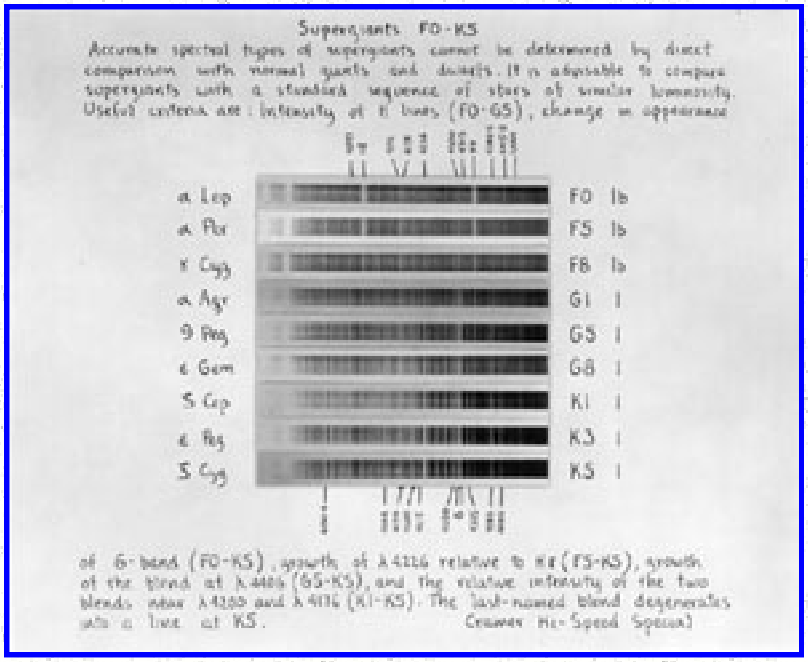
TABLE 31
THE SUPERGIANTS OF CLASSES B8-M2

Star	MKK	*a*	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	A0 Ib	06:27	+07 24	4.5	A0p	
η Leo	A0 Ib	10:01	+17 15	3.6	A0p	
a Cyg	A2 Ia	20:38	+44 55	1.3	A0p	
ν Cep	A2 Ia	21:42	+60 40	4.5	A0p	
φ Cas	A5 Ia	01:13	+57 42	5.3	F5P	
ε Aur	F0 Ia	04:54	+43 41	(3.3)	F5p	
a Lep	F0 Ib	05:28	-17 54	2.7	F0	
a 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	
a 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	
a Sco	M1 Ib	16:23	-26 13	1.2	Ma	3
μ Cep	M2 Ia	21:40	+58 19	var	Ma	3
a Ori	M2 Ib	05:49	+07 23	var	Ma	3

NOTES

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.

Plate 30. Supergiants F0 - K5



Next Contents Previous

5. FIVE COMPOSITE SPECTRA

γ Per. - From the ratios ν 4045: Hδ and ν 4226: Hγ 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 ν 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 Hδ 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.

a 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 λλ 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 [*a* 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.

a 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.

Next Contents Previous

6. 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 (Plates 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. Others stars having lines suggesting higher rotational velocities than the Bnn star, η UMa, are ζ Oph, 25 Ori, and β Mon A.

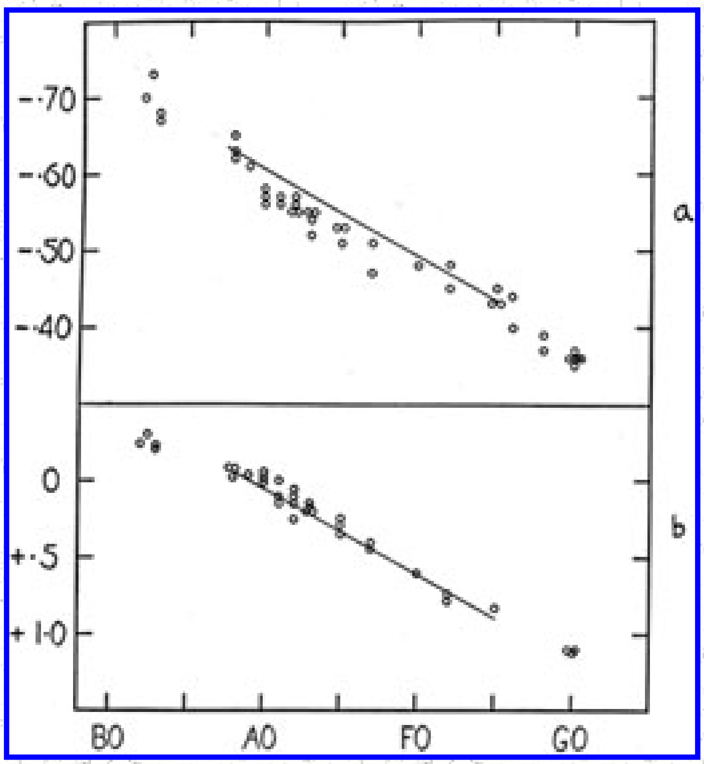


Figure 1. Color equivalents of B2-G0 main-sequence stars. The photoelectric color indices of Bottlinger (*above*) and Greenwich gradients (*below*) are plotted against the spectral types of the present *Atlas*. The stars included are those of luminosity classes IV and V which appear to be definitely 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.

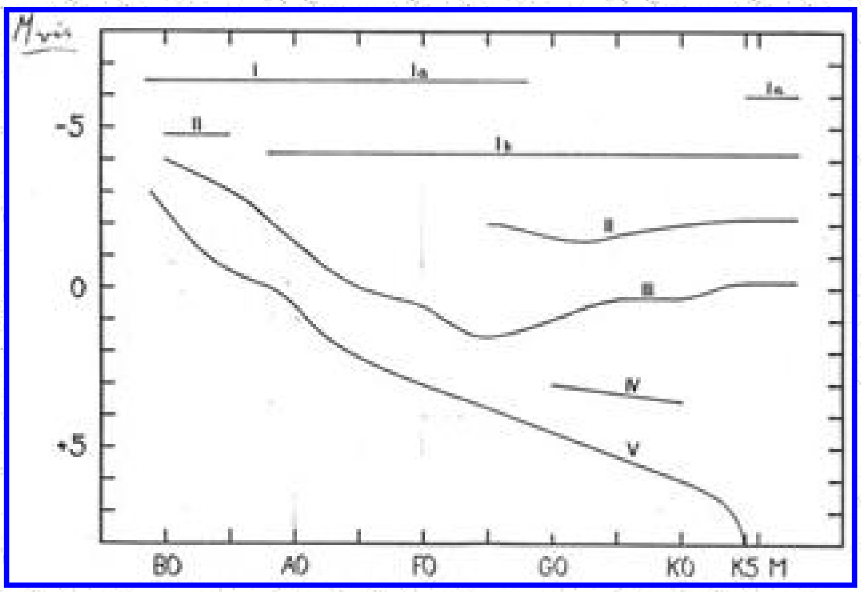


Figure 2. Preliminary calibration of luminosity classes in terms of visual absolute magnitude.

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 *a* 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).

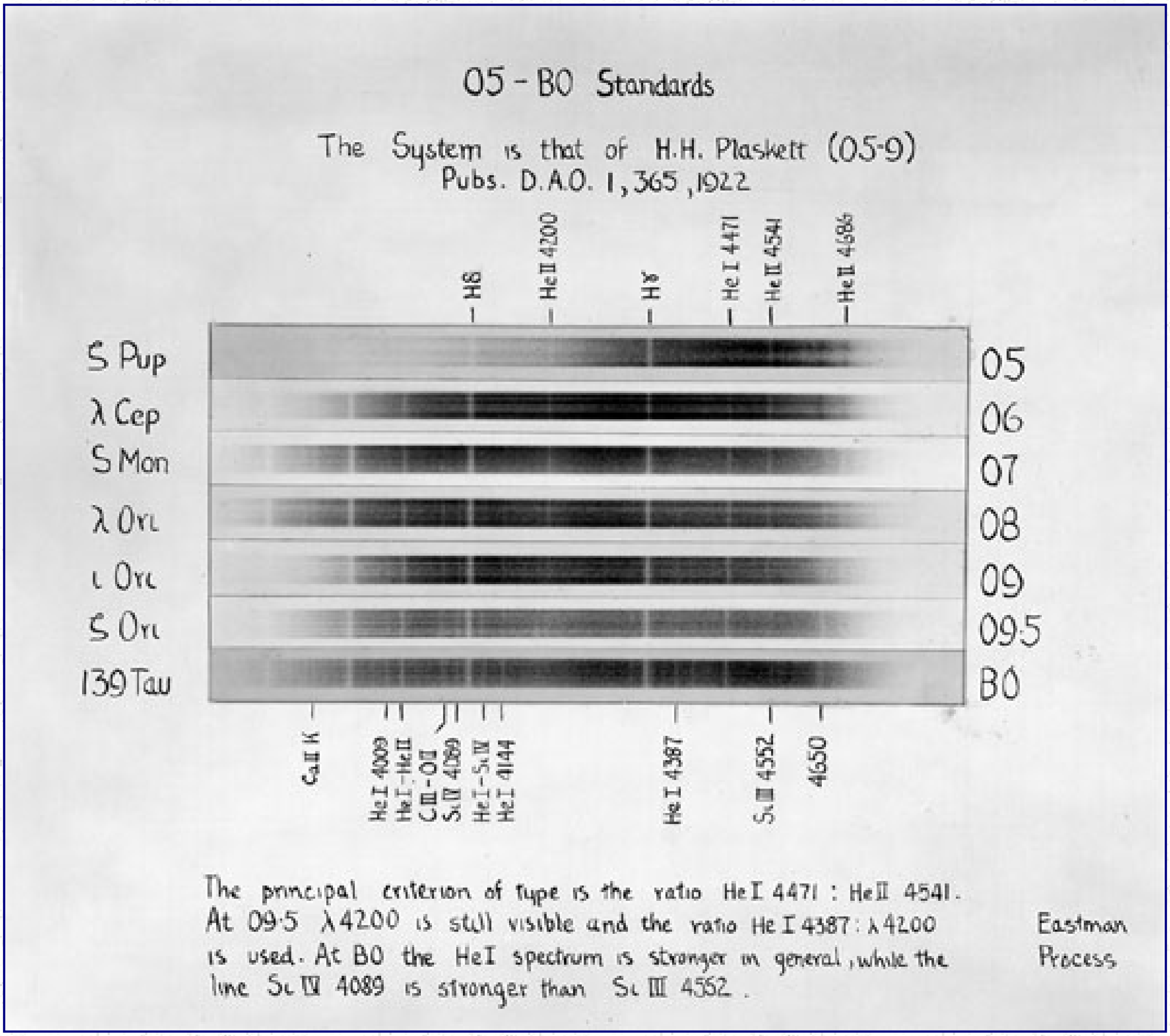
The spectral classification defines with accuracy a system of color standards which can be used in investigations of interstellar absorption and determinations of systematic errors in spectral classification of faint stars. It should be emphasized that the actual features used for classification are 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.

We wish to acknowledge our indebtedness to the following persons: to Dr. Struve for making the publication of the *Atlas* possible; to Dr. Joaquin Gallo, director of the Astronomical Observatory of Mexico at Tacubaya, for the loan of a number of objective-prism plates; to Dr. A.H. Joy, of Mount Wilson, for determining the spectral types of several M giants which we have used as standards; to Dr. A.N. Vyssotsky, of the Leander McCormick Observatory, for several discussions of the problem of spectral classification; and to Dr. G.P. Kuiper for a discussion of the dynamical parallax of δ Cygni. We are also indebted to the following persons for taking a considerable number of the spectrograms used in the investigation: Mrs. Frances Sherman Bailey, Dr. J.A. O'Keefe, Dr. L.R. Henrich, Mr. W.P. Bidelman, and Mr. Frank R. Sullivan. All the photographic prints for the *Atlas* were made by Miss Kellman and Miss Phyllis Anderson.

Contents Previous

Next Contents

Plate 1



Next | Contents | Previous

Plate 2

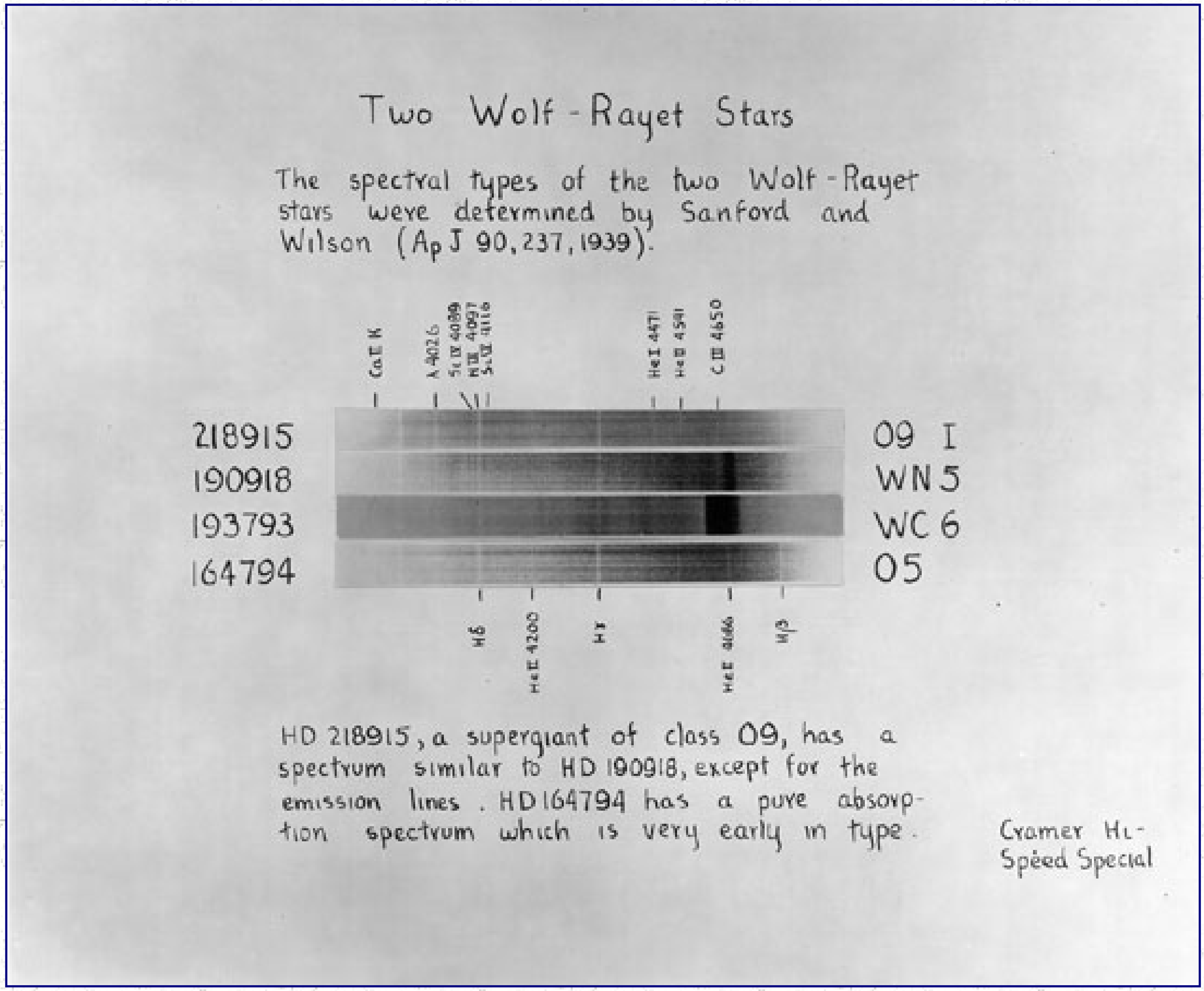


Plate 3

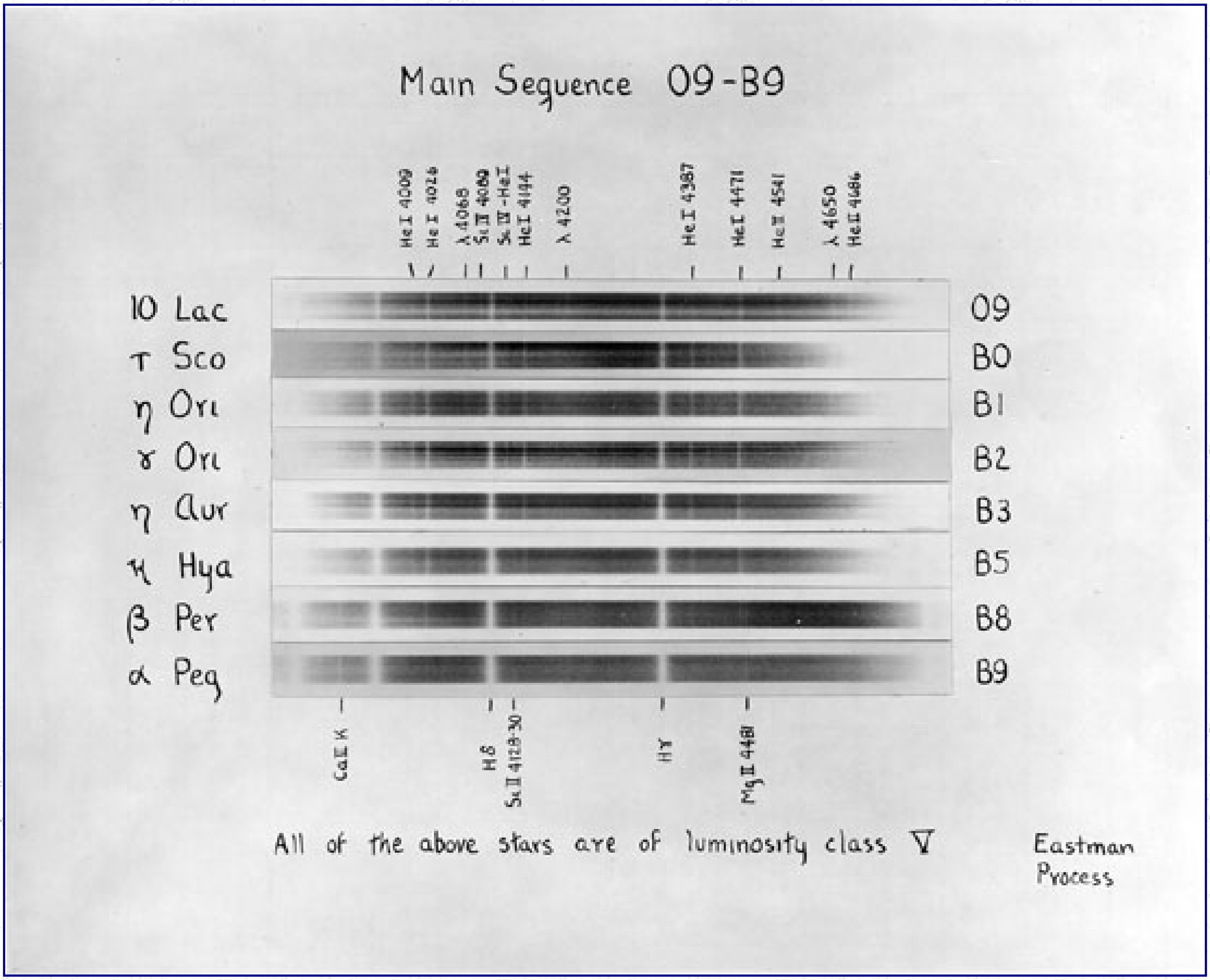

Main Sequence O9-B9
He I 4009
He I 4026
λ 4068
Si IV 4089
Si IV-He I
He I 4144
λ 4200
He I 4387
He I 4471
He II 4541
λ 4650
He II 4686
10 Lac
τ Sco
η Ori
γ Ori
η Aur
ι Hya
β Per
α Peg
O9
B0
B1
B2
B3
B5
B8
B9
Ca II K
Hδ
Si II 4128-30
Hγ
Mg II 4481
All of the above stars are of luminosity class V
Eastman Process

Plate 4

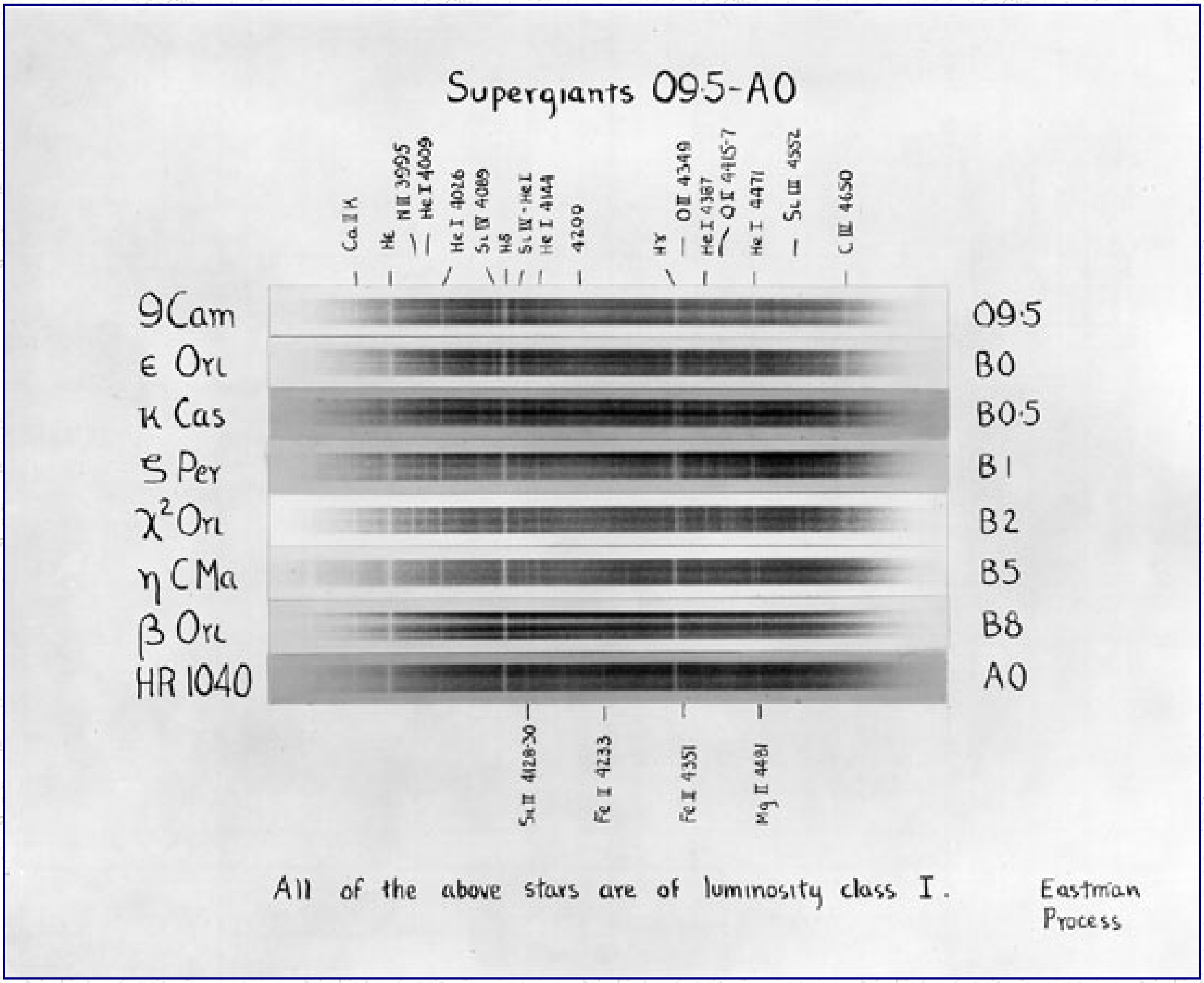

Supergiants O9.5-A0
Ca II K
Hε
N II 3995
He I 4009
He I 4026
Si IV 4089
Hδ
Si IV - He I
He I 4144
4200
Hγ
O II 4349
He I 4387
O II 4415-7
He I 4471
Si III 4552
C III 4650
9 Cam
ε Ori
κ Cas
ζ Per
χ² Ori
η CMa
β Ori
HR 1040
O9.5
B0
B0.5
B1
B2
B5
B8
A0
Si II 4128-30
Fe I 4233
Fe II 4351
Mg II 4481
All of the above stars are of luminosity class I.
Eastman Process

Plate 5

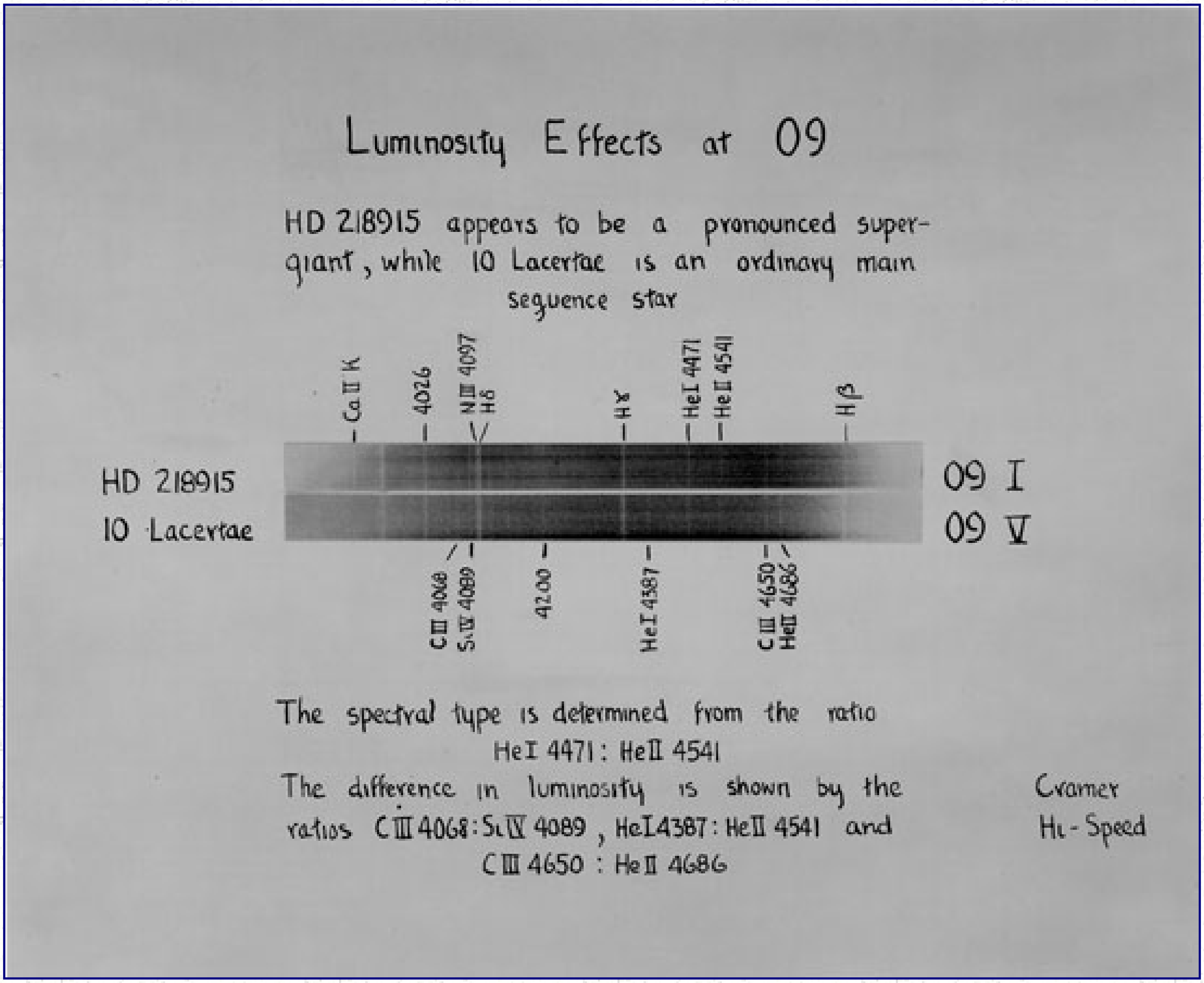

Luminosity Effects at O9
HD 218915 appears to be a pronounced super-giant, while 10 Lacertae is an ordinary main sequence star
Ca II K
4026
N III 4097
Hδ
Hγ
He I 4471
He II 4541
Hβ
HD 218915
10 Lacertae
O9 I
O9 V
C III 4068
Si IV 4089
4200
He I 4387
C III 4650
He II 4686
The spectral type is determined from the ratio
He I 4471 : He II 4541
The difference in luminosity is shown by the ratios C III 4068 : Si IV 4089, He I 4387 : He II 4541 and
C III 4650 : He II 4686
Cramer
Hi - Speed

Plate 6

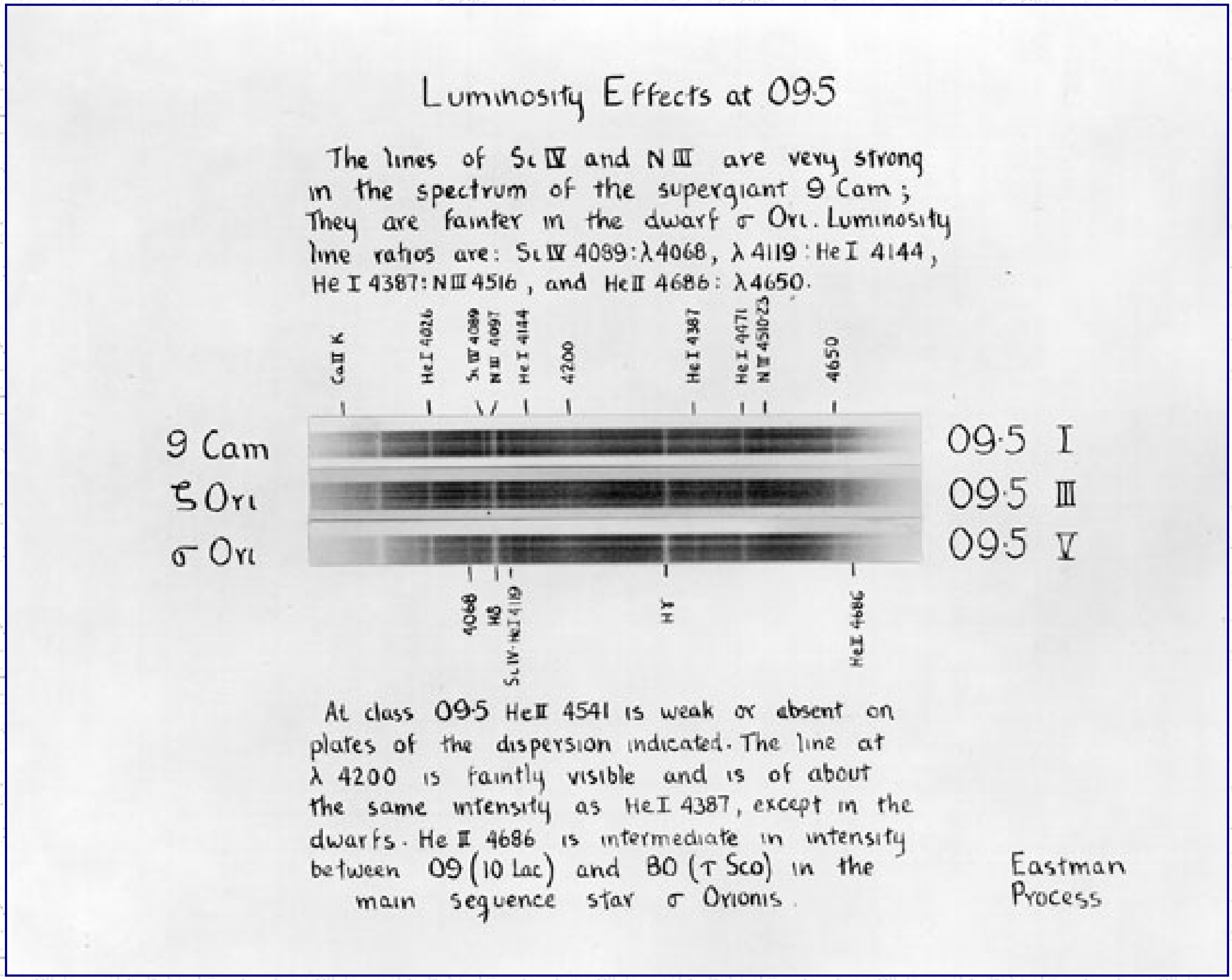
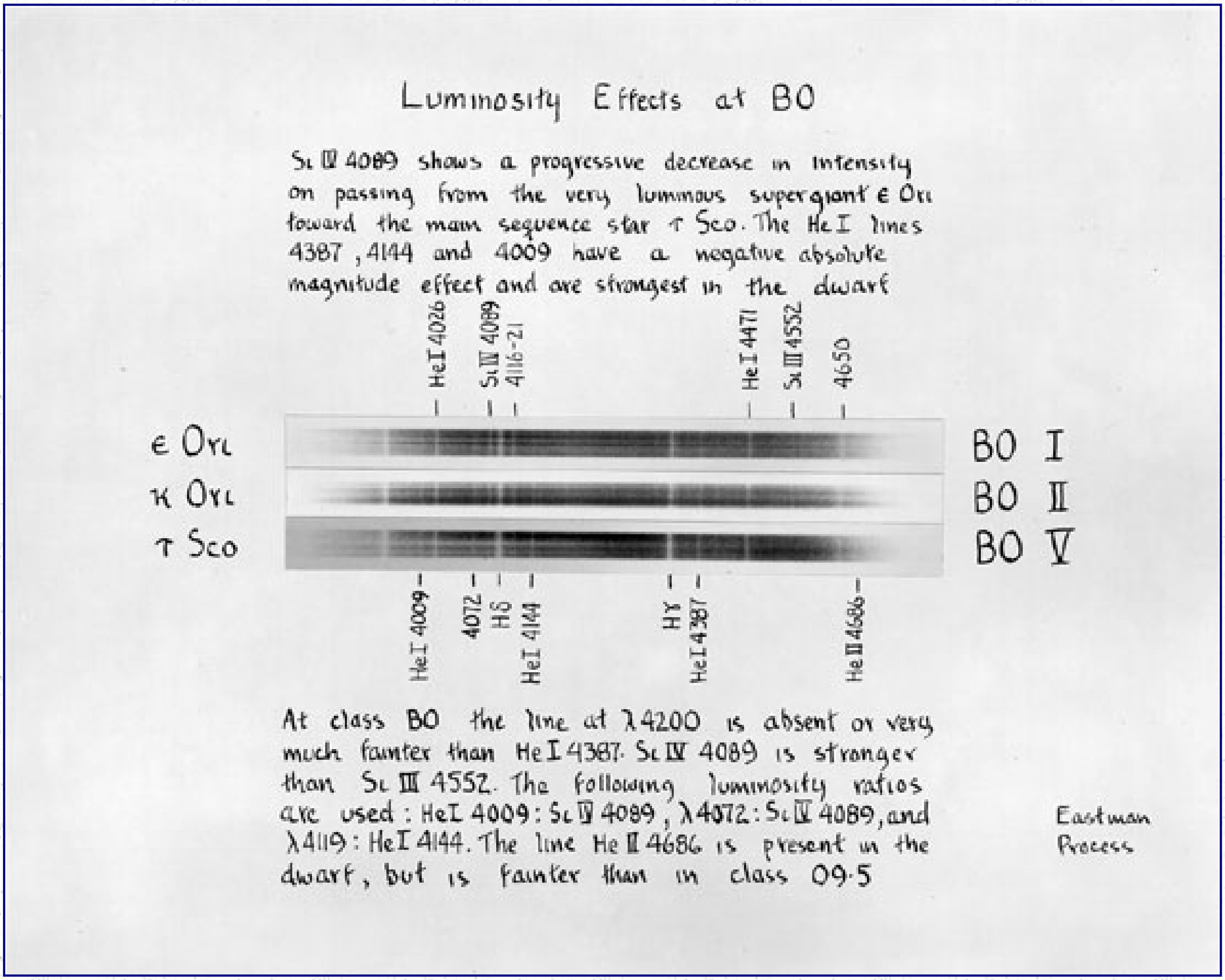

Luminosity Effects at O9.5
The lines of Si IV and N III are very strong in the spectrum of the supergiant 9 Cam; They are fainter in the dwarf σ Ori. Luminosity line ratios are: Si IV 4089 : λ4068, λ4119 : He I 4144, He I 4387 : N III 4516, and He II 4686 : λ4650.
Ca II K
He I 4026
Si IV 4089
N III 4097
He I 4144
4200
He I 4387
He I 4471
N III 4510-23
4650
9 Cam
ζ Ori
σ Ori
O9.5 I
O9.5 III
O9.5 V
4068
Hδ
Si IV-He I 4119
Hγ
He II 4686
At class O9.5 He II 4541 is weak or absent on plates of the dispersion indicated. The line at λ 4200 is faintly visible and is of about the same intensity as He I 4387, except in the dwarfs. He II 4686 is intermediate in intensity between O9 (10 Lac) and B0 (τ Sco) in the main sequence star σ Orionis.
Eastman Process

Plate 7


Luminosity Effects at B0
Si IV 4089 shows a progressive decrease in intensity on passing from the very luminous supergiant ε Ori toward the main sequence star τ Sco. The He I lines 4387, 4144 and 4009 have a negative absolute magnitude effect and are strongest in the dwarf
He I 4026
Si IV 4089
4116-21
He I 4471
Si III 4552
4650
ε Ori
κ Ori
τ Sco
B0 I
B0 II
B0 V
He I 4009
4072
Hδ
He I 4144
Hγ
He I 4387
He II 4686
At class B0 the line at λ4200 is absent or very much fainter than He I 4387. Si IV 4089 is stronger than Si III 4552. The following luminosity ratios are used: He I 4009 : Si IV 4089, λ4072 : Si IV 4089, and λ4119 : He I 4144. The line He II 4686 is present in the dwarf, but is fainter than in class O9.5
Eastman Process

Next Contents Previous

Plate 8

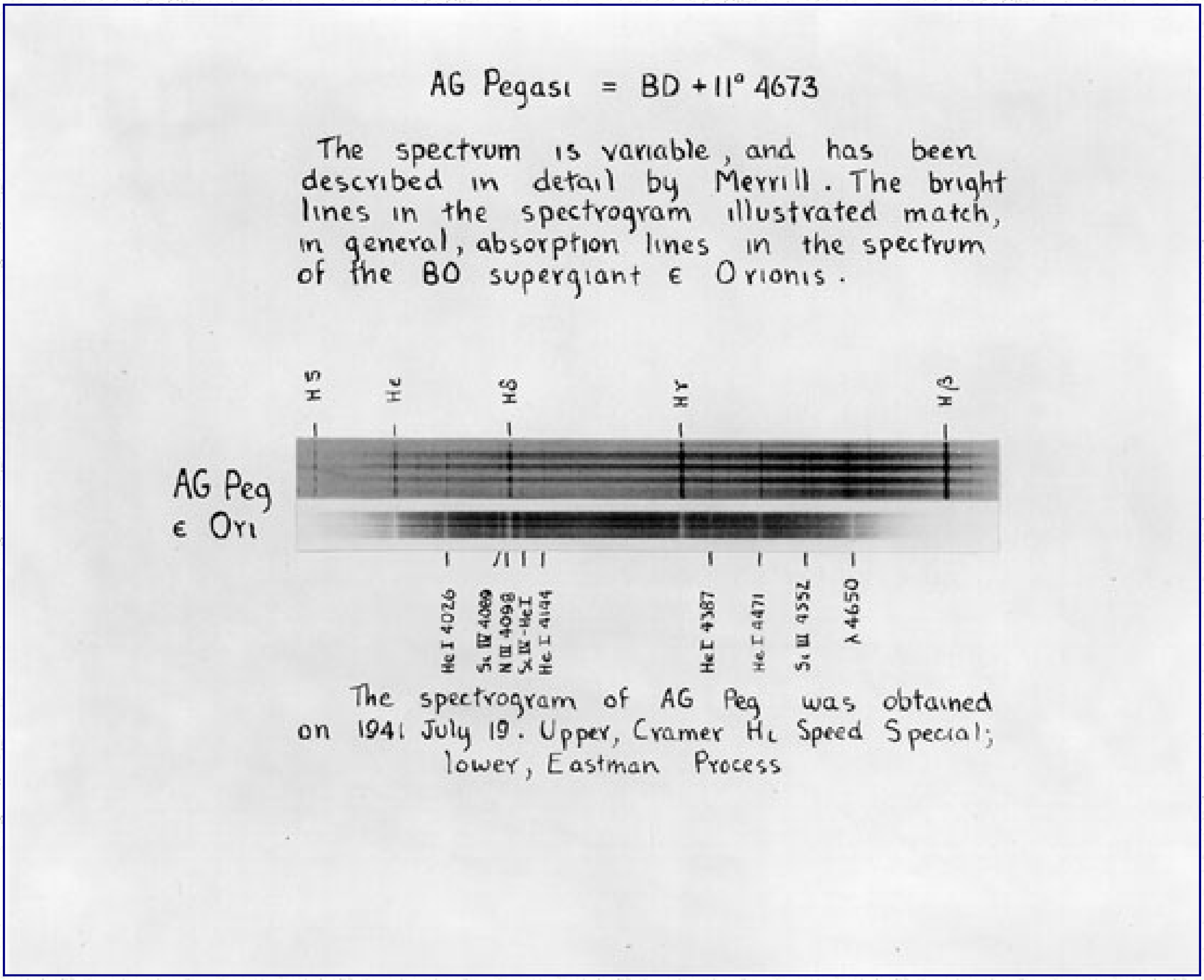
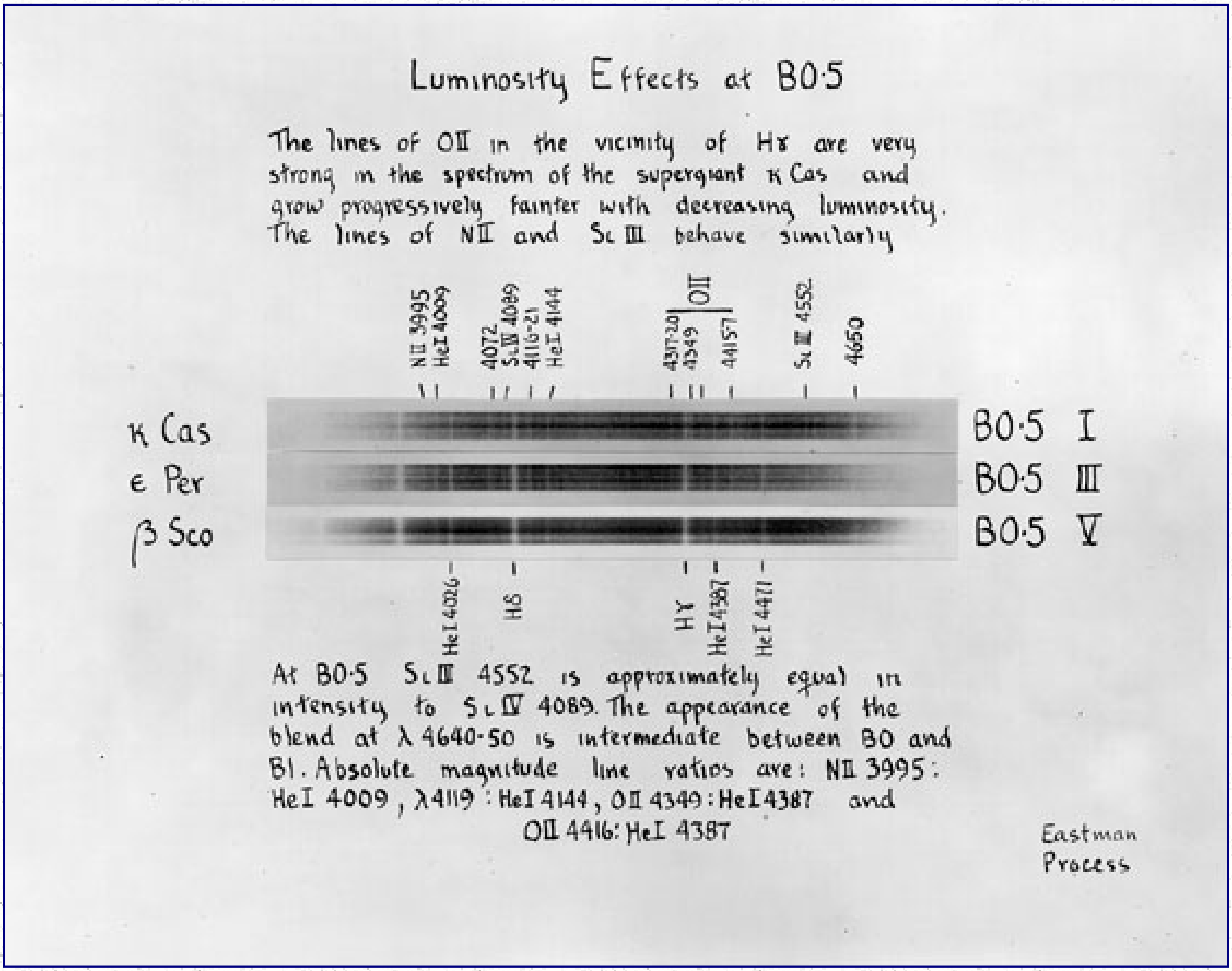
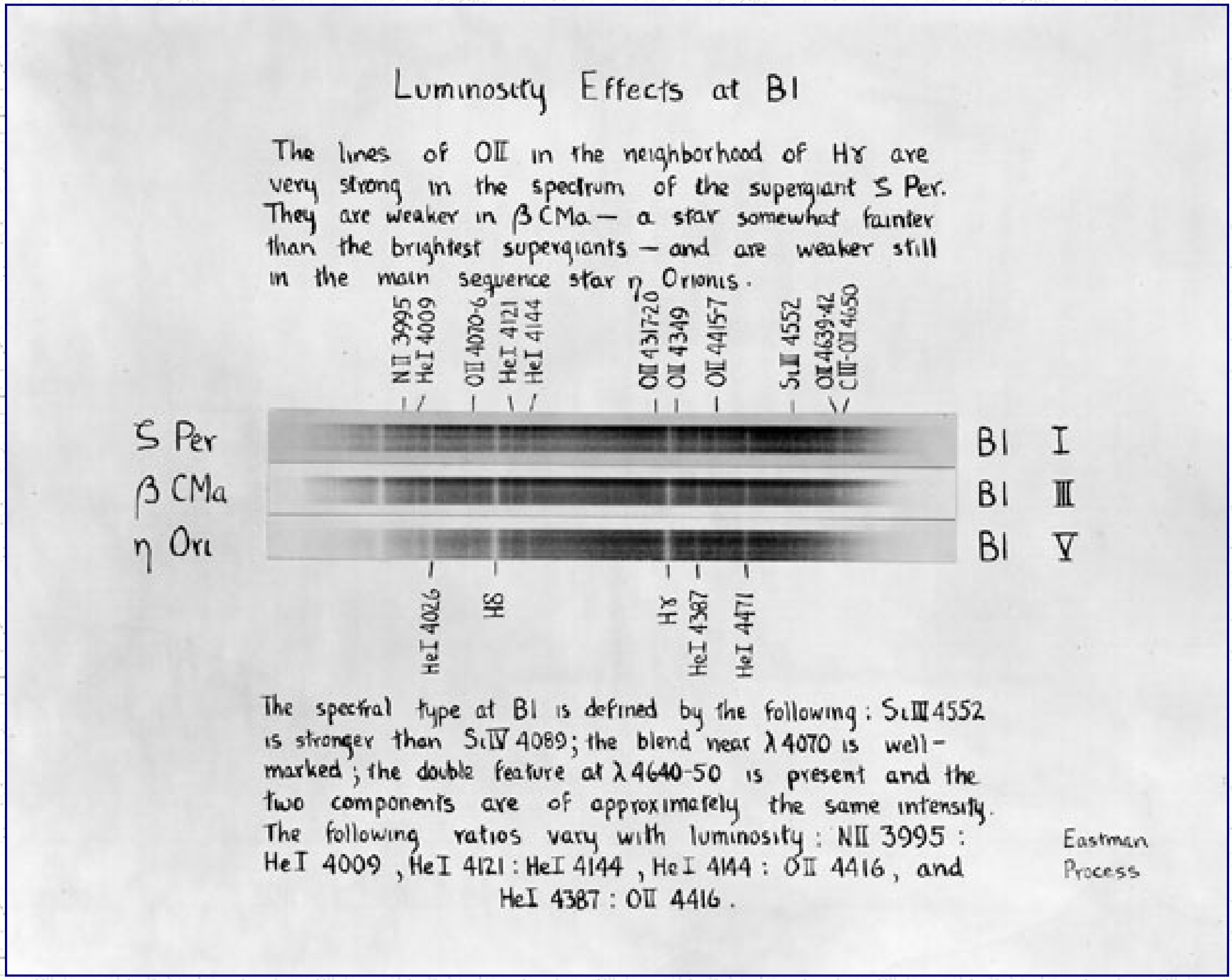


Plate 9


Luminosity Effects at B0·5
The lines of OII in the vicinity of Hγ are very strong in the spectrum of the supergiant κ Cas and grow progressively fainter with decreasing luminosity. The lines of NII and Si III behave similarly
NII 3995
HeI 4009
4072
Si IV 4089
4116-21
HeI 4144
4317-20
4349
4415-17
OII
Si III 4552
4650
κ Cas
ε Per
β Sco
B0·5 I
B0·5 III
B0·5 V
HeI 4026
Hδ
Hγ
HeI 4387
HeI 4471
At B0·5 Si III 4552 is approximately equal in intensity to Si IV 4089. The appearance of the blend at λ 4640-50 is intermediate between B0 and B1. Absolute magnitude line ratios are: NII 3995 : HeI 4009, λ4119 : HeI 4144, OII 4349 : HeI 4387 and OII 4416 : HeI 4387
Eastman Process

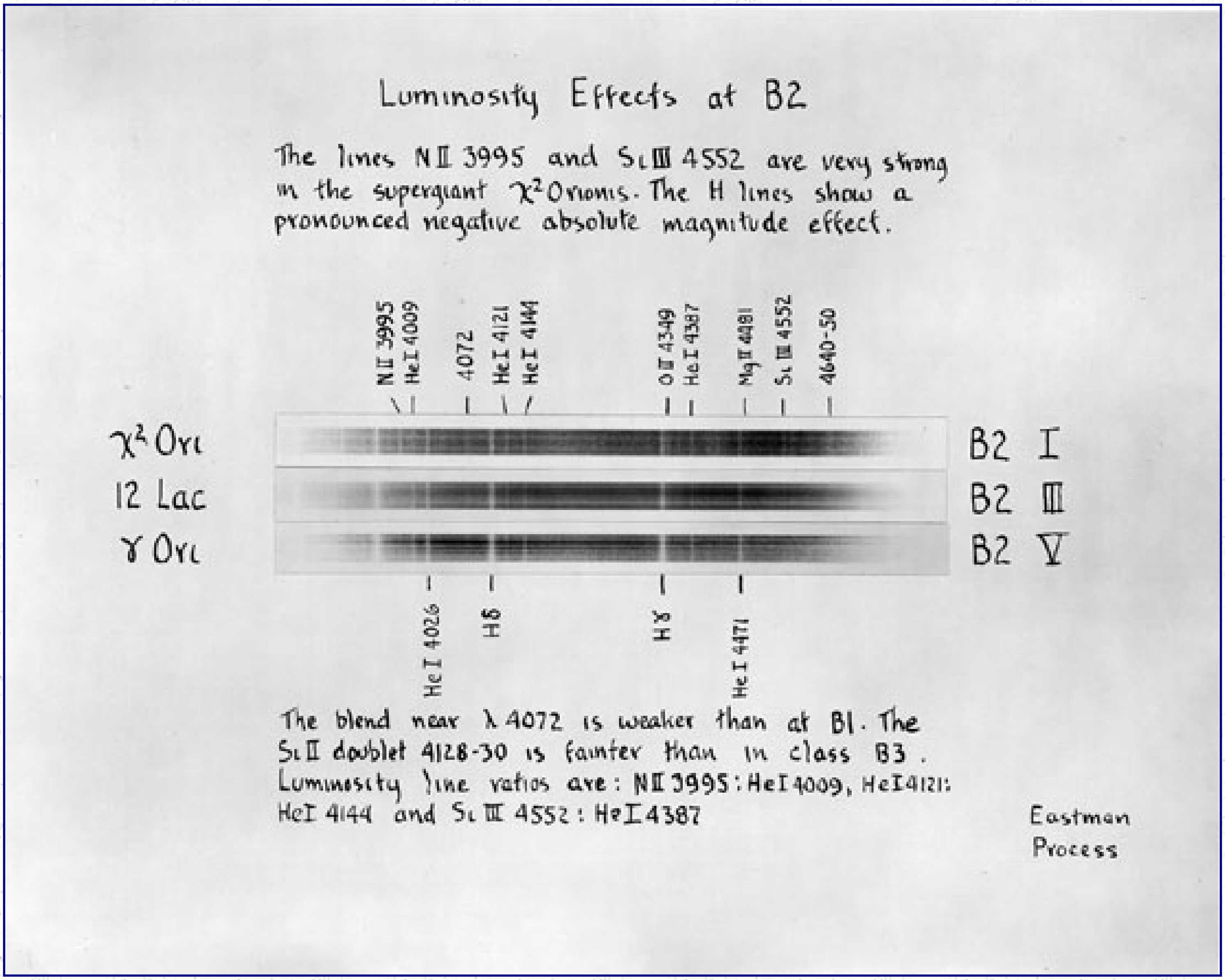
Next Contents Previous

Plate 10



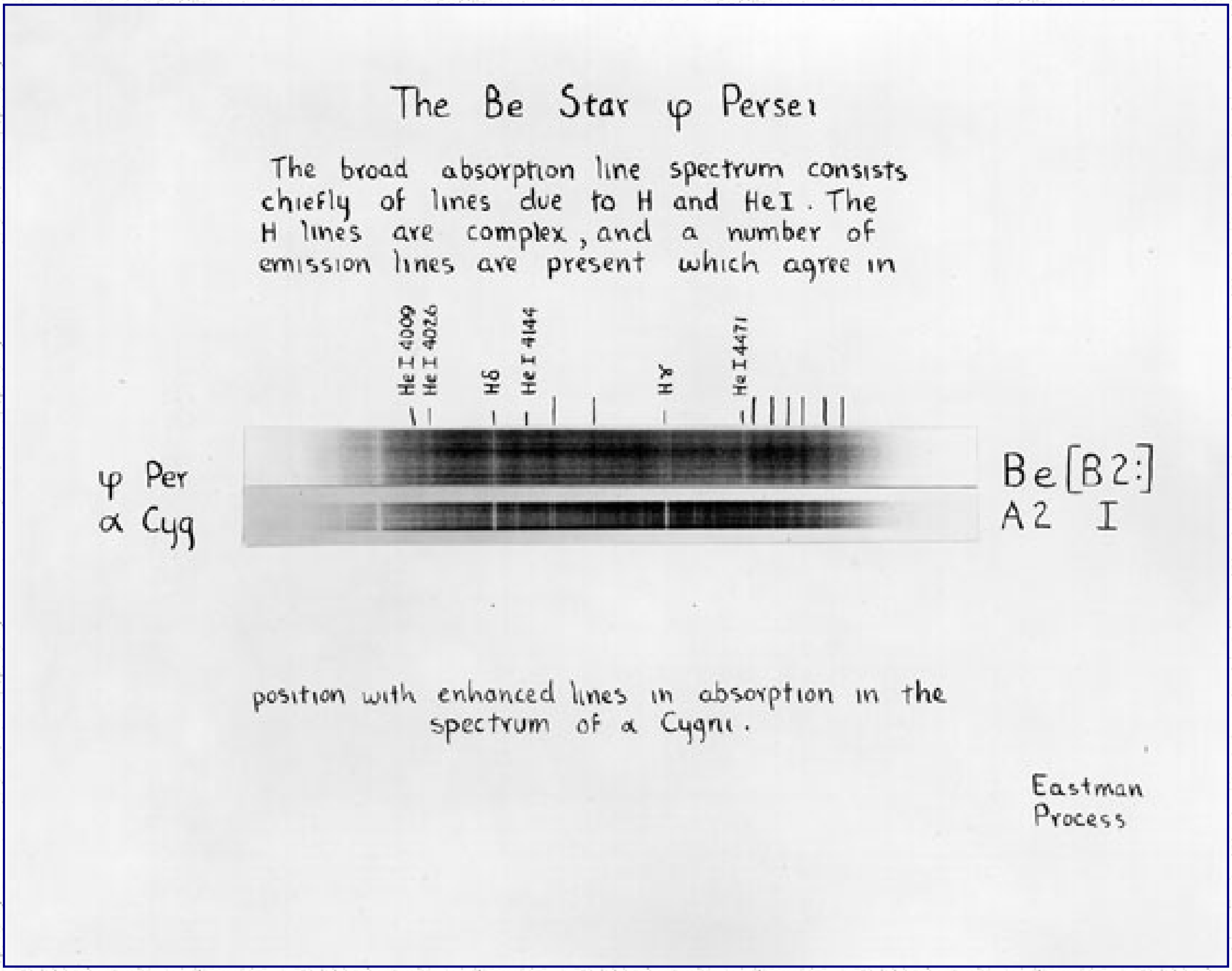
Next Contents Previous

Plate 11



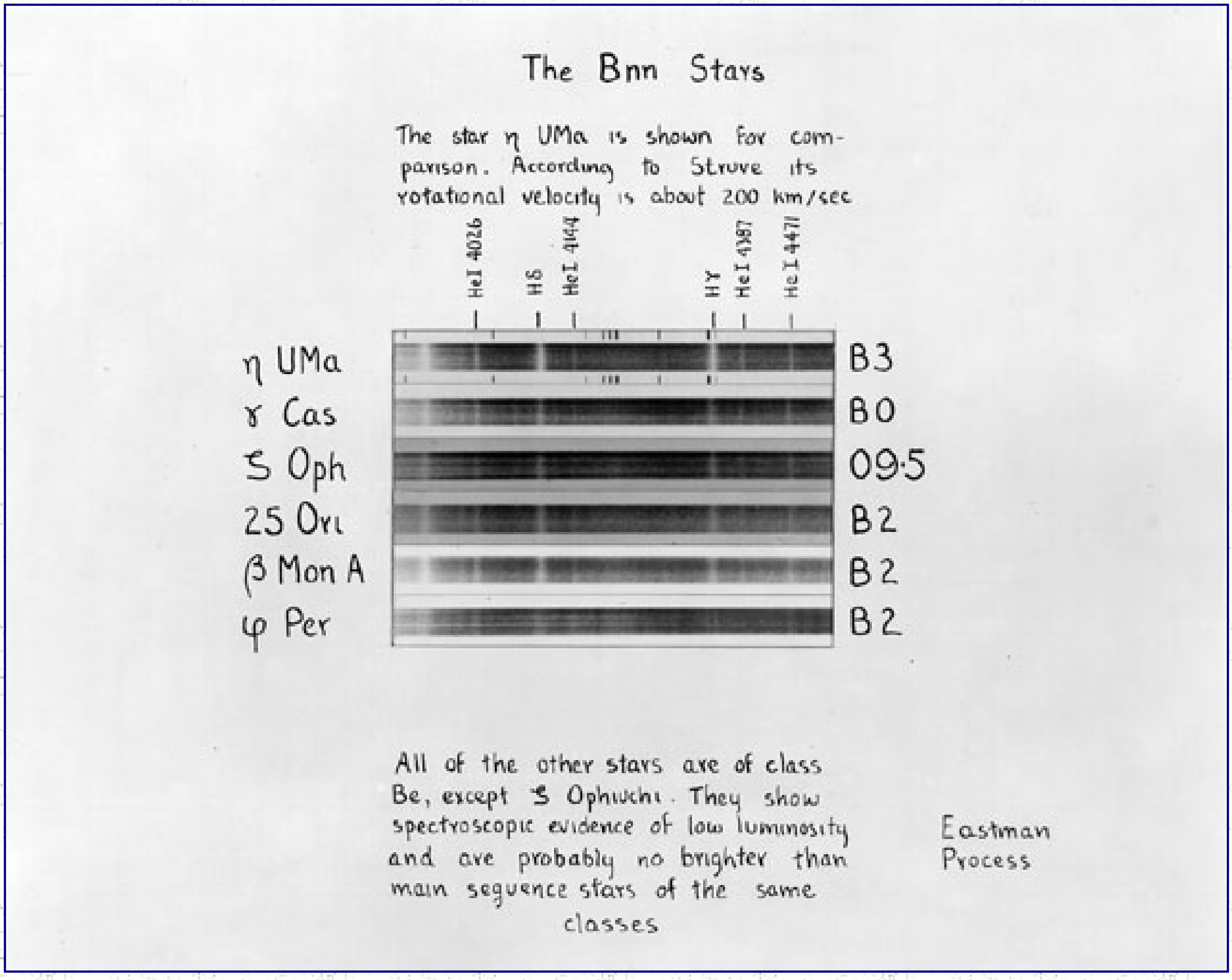
Next Contents Previous

Plate 12



Next Contents Previous

Plate 13



Next Contents Previous

Plate 14

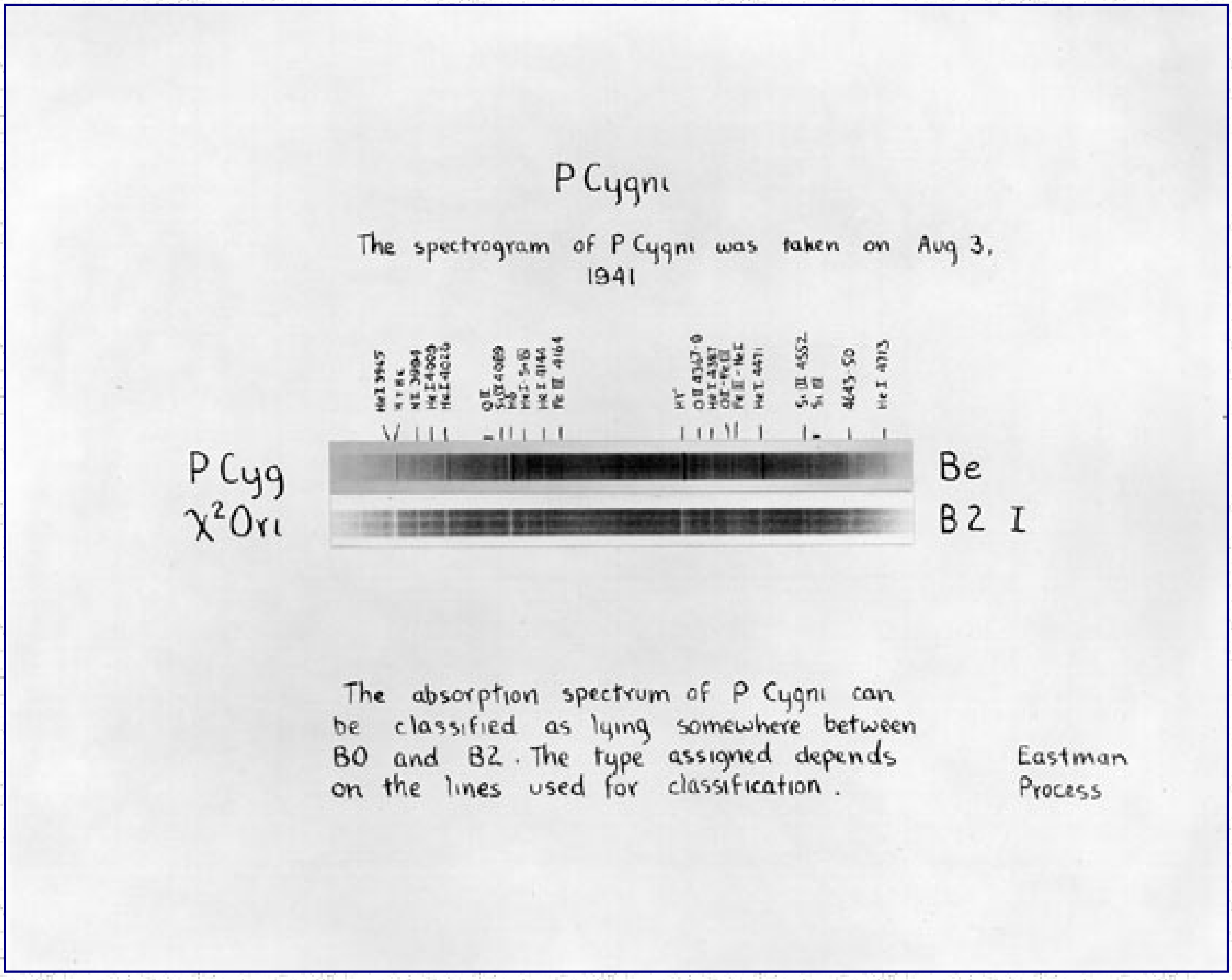


Plate 15

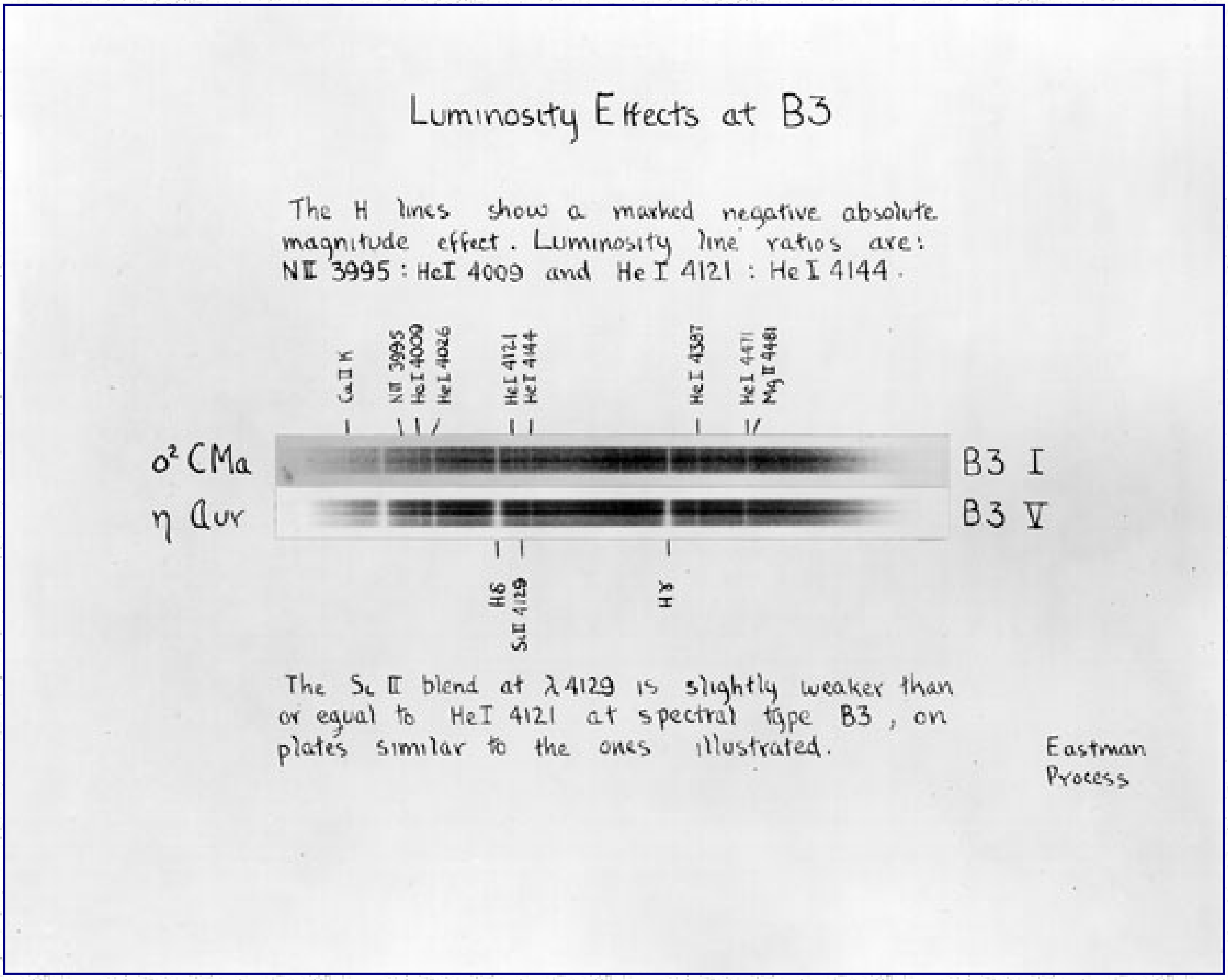
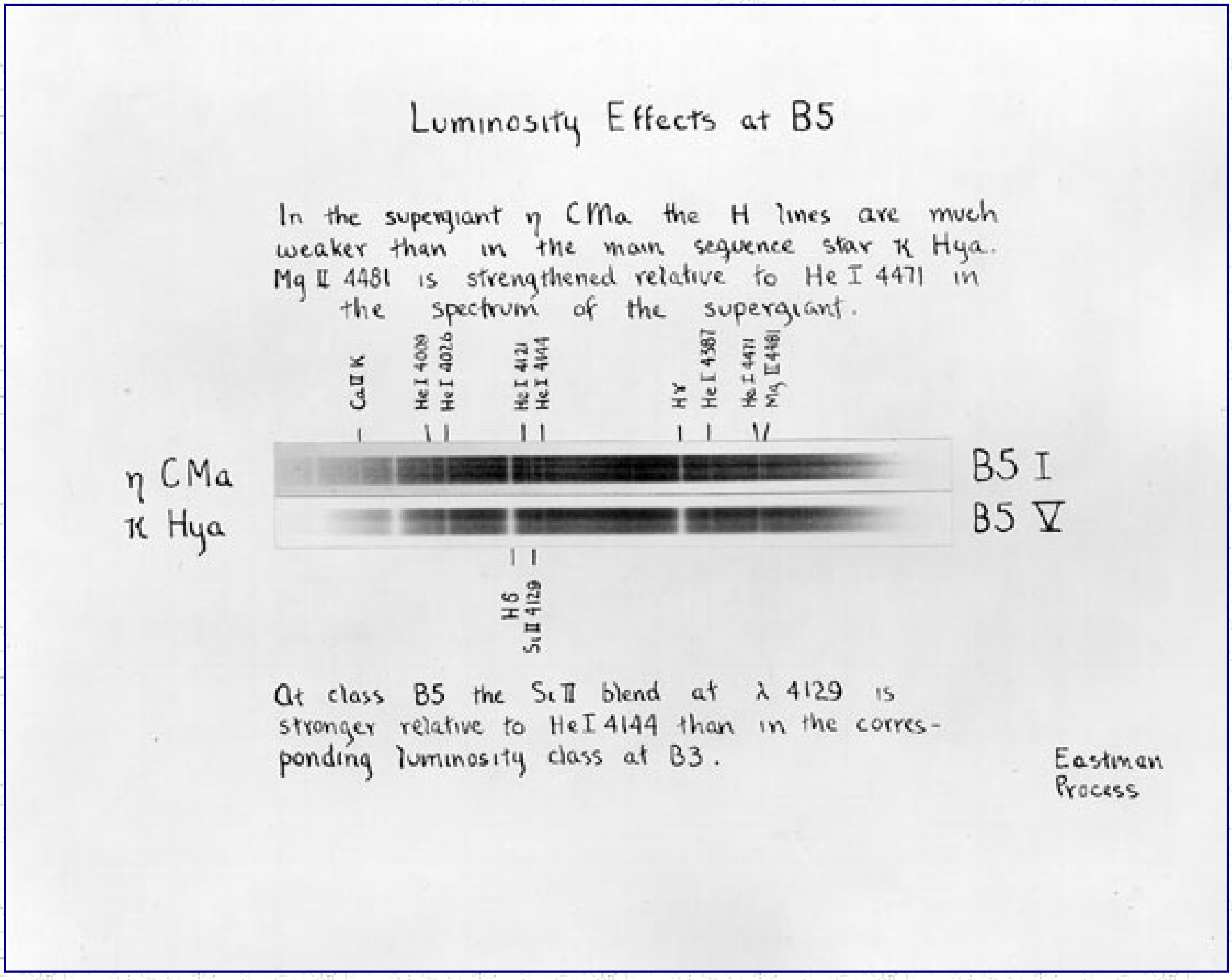

Luminosity Effects at B3
The H lines show a marked negative absolute magnitude effect. Luminosity line ratios are: N II 3995 : He I 4009 and He I 4121 : He I 4144.
Ca II K
N II 3995
He I 4009
He I 4026
He I 4121
He I 4144
He I 4387
He I 4471
Mg II 4481
o² CMa
η Aur
B3 I
B3 V
Hδ
Si II 4129
Hγ
The Si II blend at λ4129 is slightly weaker than or equal to He I 4121 at spectral type B3, on plates similar to the ones illustrated.
Eastman Process

Plate 16



Luminosity Effects at B5
In the supergiant η CMa the H lines are much weaker than in the main sequence star κ Hya. Mg II 4481 is strengthened relative to He I 4471 in the spectrum of the supergiant.
Ca II K
He I 4009
He I 4026
He I 4121
He I 4144
Hγ
He I 4387
He I 4471
Mg II 4481
η CMa
κ Hya
B5 I
B5 V
Hδ
Si II 4129
At class B5 the Si II blend at λ 4129 is stronger relative to He I 4144 than in the corresponding luminosity class at B3.
Eastman Process

Plate 17

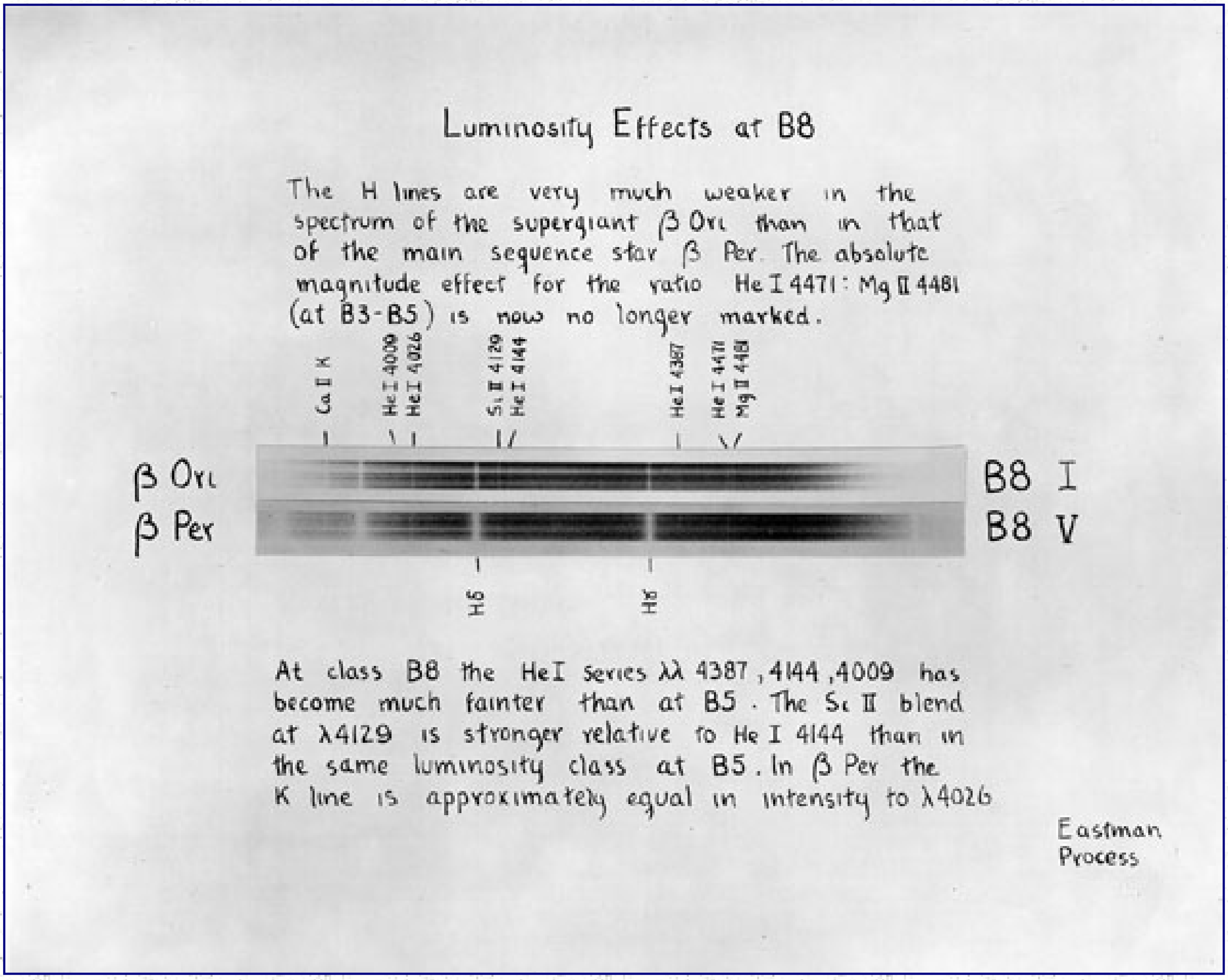

Luminosity Effects at B8
The H lines are very much weaker in the spectrum of the supergiant β Ori than in that of the main sequence star β Per. The absolute magnitude effect for the ratio He I 4471 : Mg II 4481 (at B3-B5) is now no longer marked.
Ca II K
He I 4009
He I 4026
Si II 4129
He I 4144
He I 4387
He I 4471
Mg II 4481
β Ori
β Per
B8 I
B8 V
Hδ
Hγ
At class B8 the He I series λλ 4387, 4144, 4009 has become much fainter than at B5. The Si II blend at λ4129 is stronger relative to He I 4144 than in the same luminosity class at B5. In β Per the K line is approximately equal in intensity to λ4026
Eastman Process

Plate 18

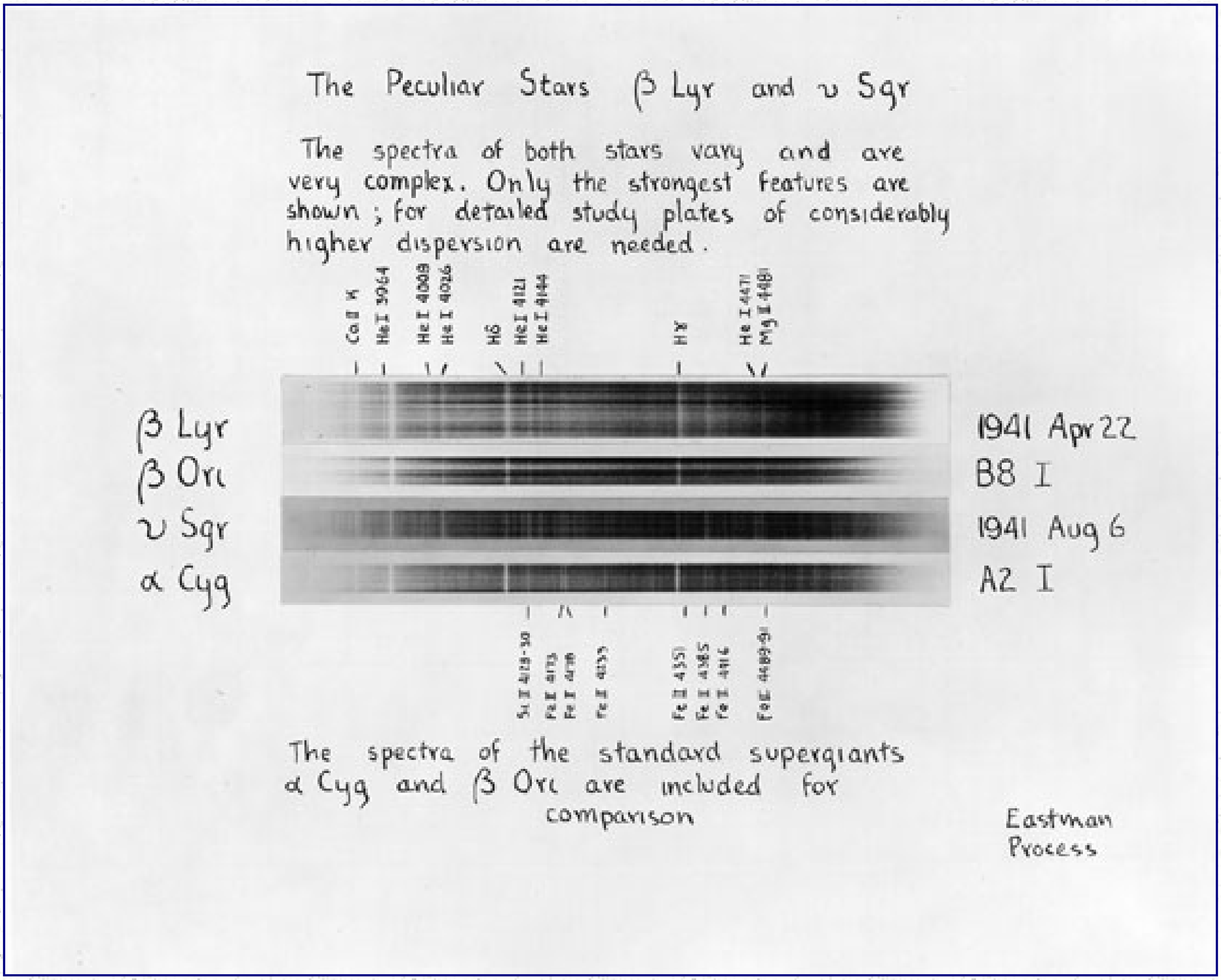
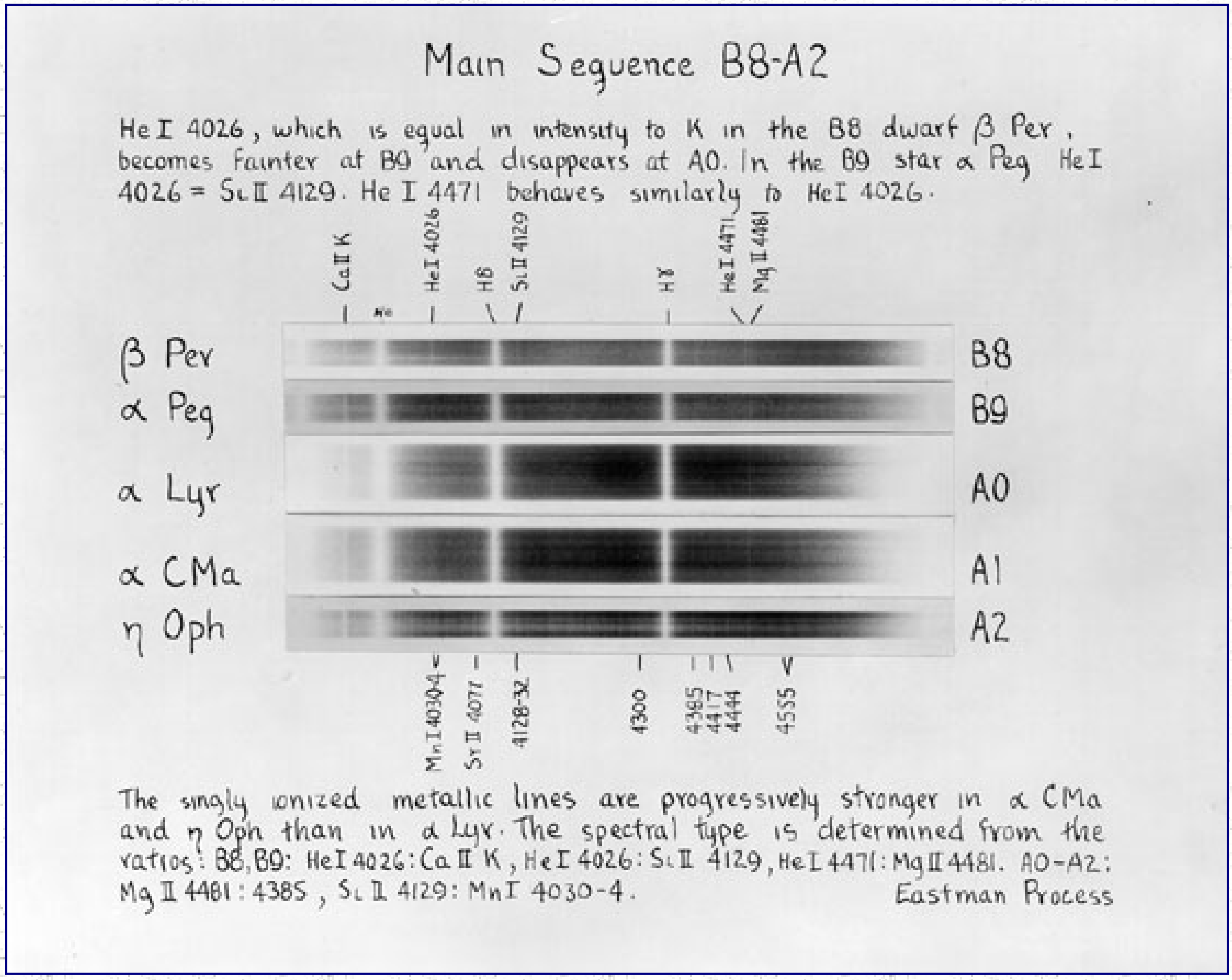

The Peculiar Stars β Lyr and υ Sgr
The spectra of both stars vary and are very complex. Only the strongest features are shown; for detailed study plates of considerably higher dispersion are needed.
Ca II K
He I 3964
He I 4009
He I 4026
Hδ
He I 4121
He I 4144
Hγ
He I 4471
Mg II 4481
β Lyr
β Ori
υ Sgr
α Cyg
1941 Apr 22
B8 I
1941 Aug 6
A2 I
The spectra of the standard supergiants α Cyg and β Ori are included for comparison
Eastman Process

Plate 19


Main Sequence B8-A2
He I 4026, which is equal in intensity to K in the B8 dwarf β Per, becomes fainter at B9 and disappears at A0. In the B9 star α Peg He I 4026 = Si II 4129. He I 4471 behaves similarly to He I 4026.
Ca II K
He I 4026
Hδ
Si II 4129
Hγ
He I 4471
Mg II 4481
β Per
α Peg
α Lyr
α CMa
η Oph
B8
B9
A0
A1
A2
Mn I 4030-4
Sr II 4077
4128-32
4300
4385
4417
4444
4555
The singly ionized metallic lines are progressively stronger in α CMa and η Oph than in α Lyr. The spectral type is determined from the ratios: B8, B9: He I 4026 : Ca II K, He I 4026 : Si II 4129, He I 4471 : Mg II 4481. A0-A2: Mg II 4481 : 4385, Si II 4129 : Mn I 4030-4.
Eastman Process

Next Contents Previous

Plate 20

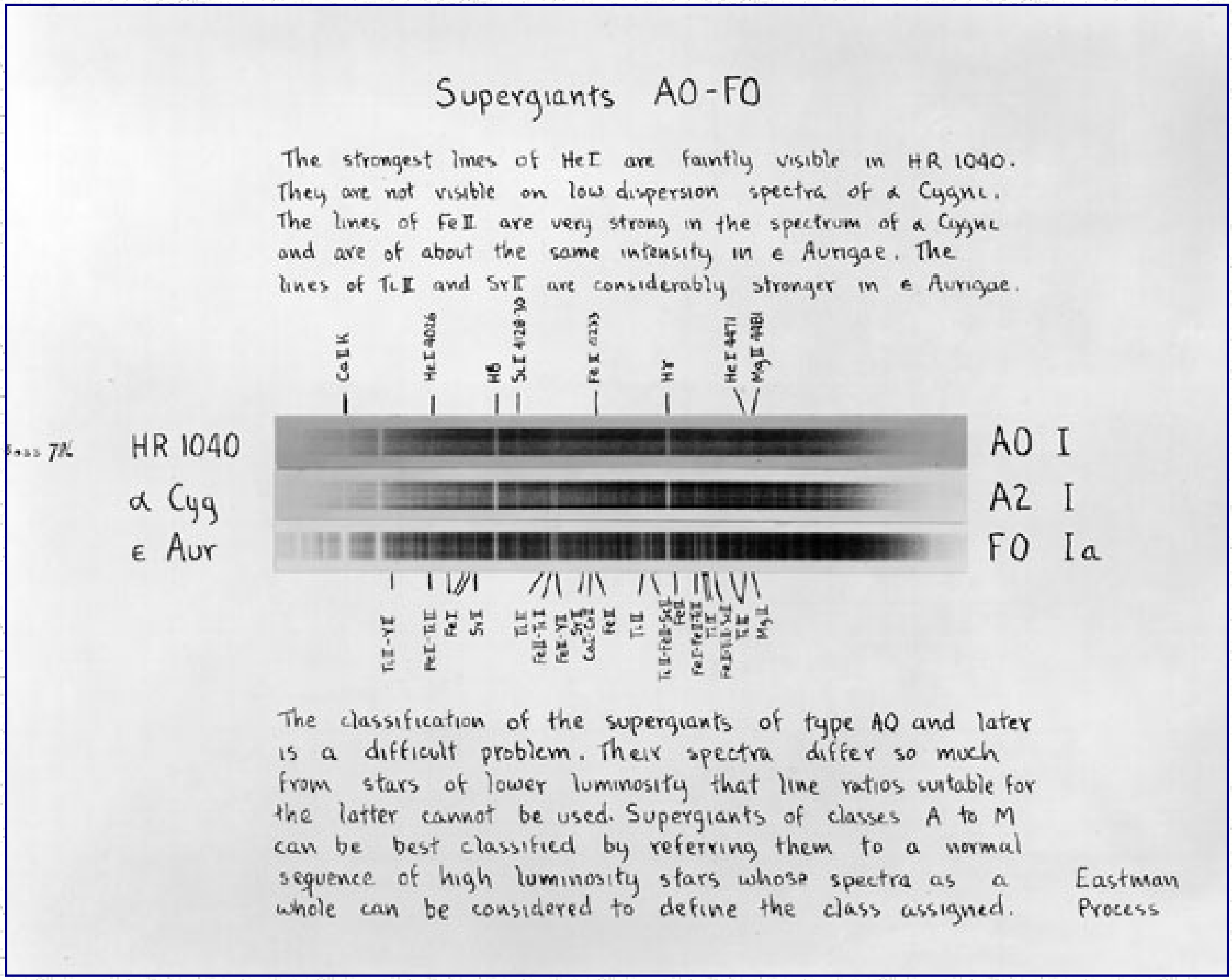


Plate 21

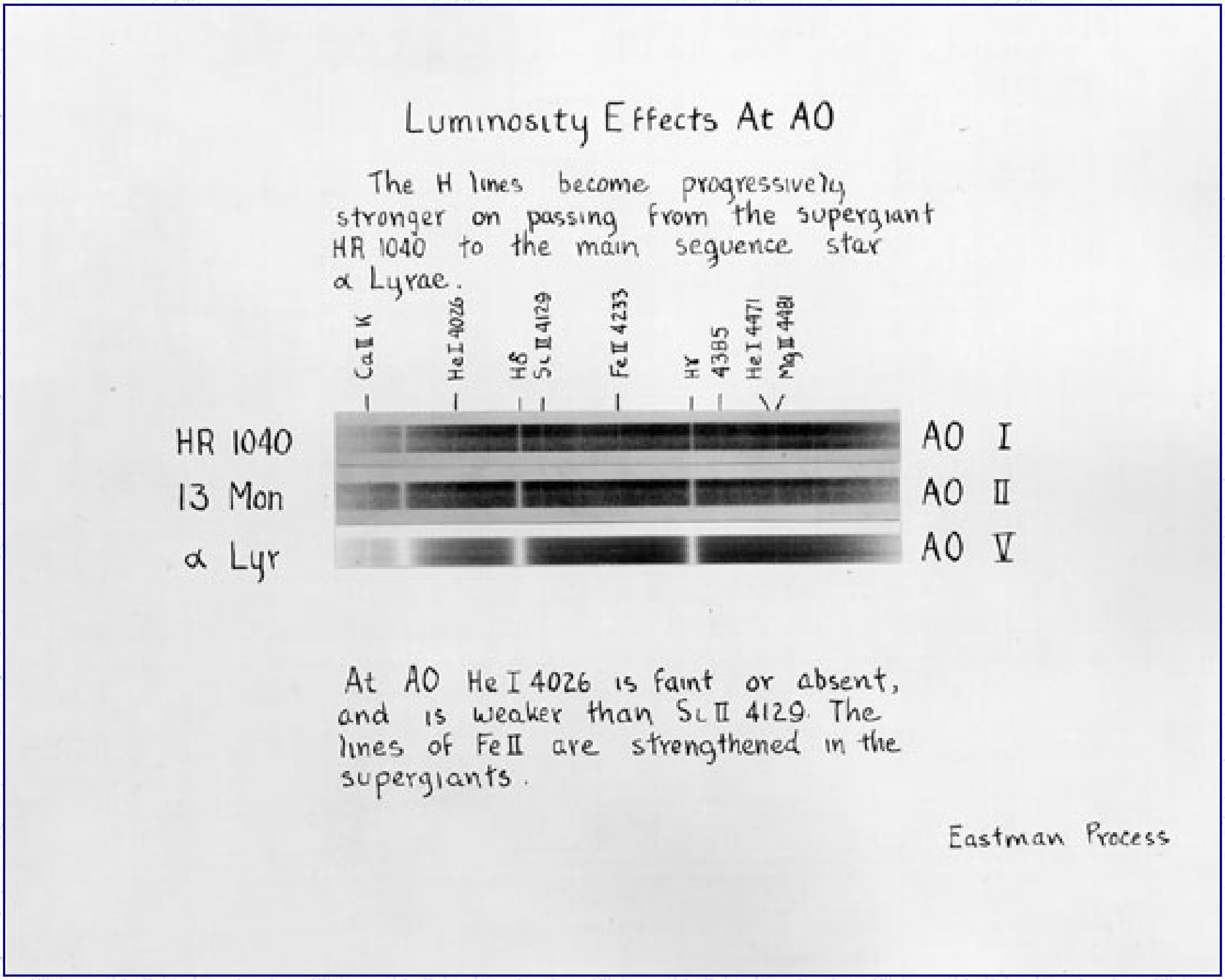

Luminosity Effects At A0
The H lines become progressively stronger on passing from the supergiant HR 1040 to the main sequence star α Lyrae.
Ca II K
He I 4026
Hδ
Si II 4129
Fe II 4233
Hγ
4385
He I 4471
Mg II 4481
HR 1040
13 Mon
α Lyr
A0 I
A0 II
A0 V
At A0 He I 4026 is faint or absent, and is weaker than Si II 4129. The lines of Fe II are strengthened in the supergiants.
Eastman Process

Plate 22

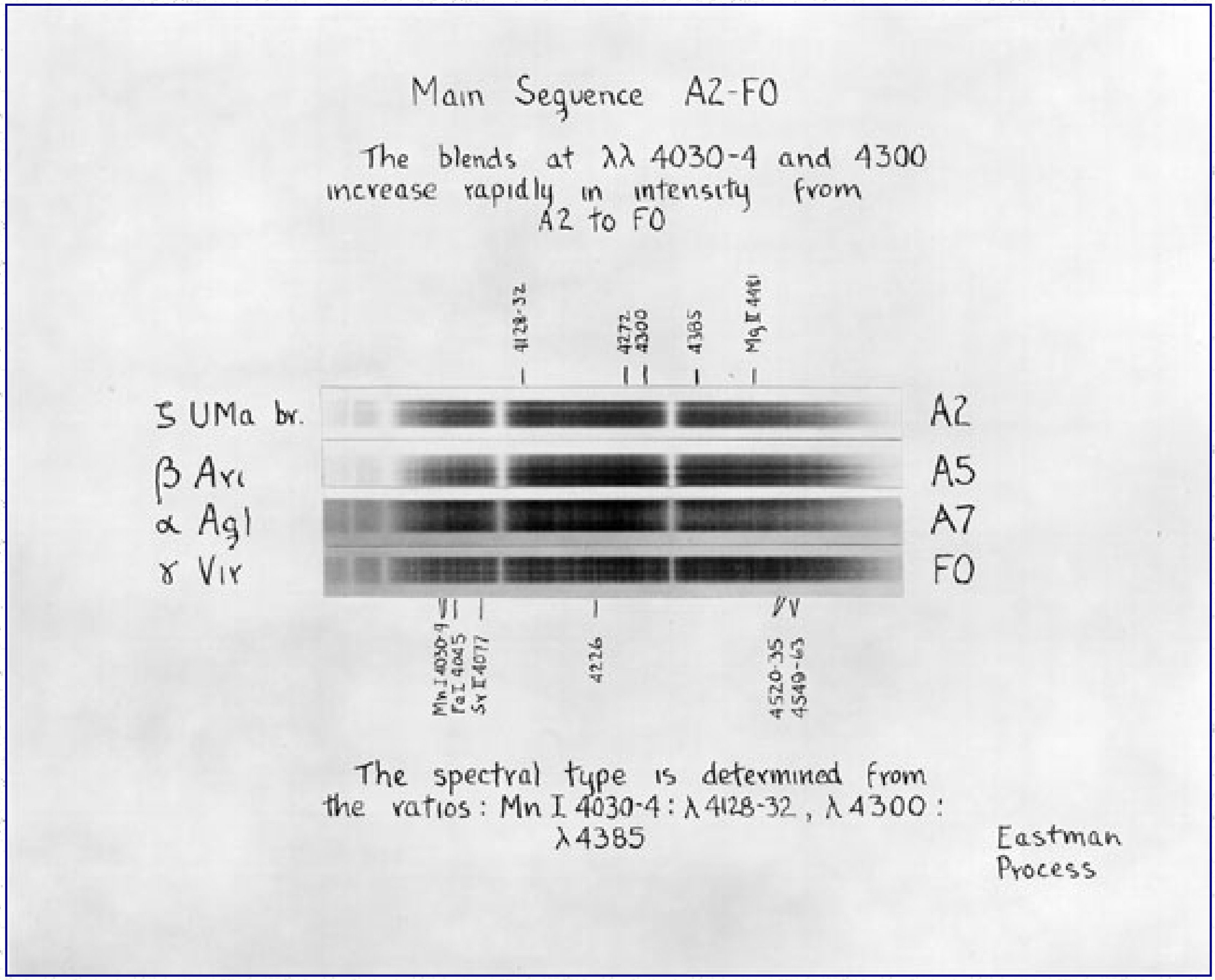
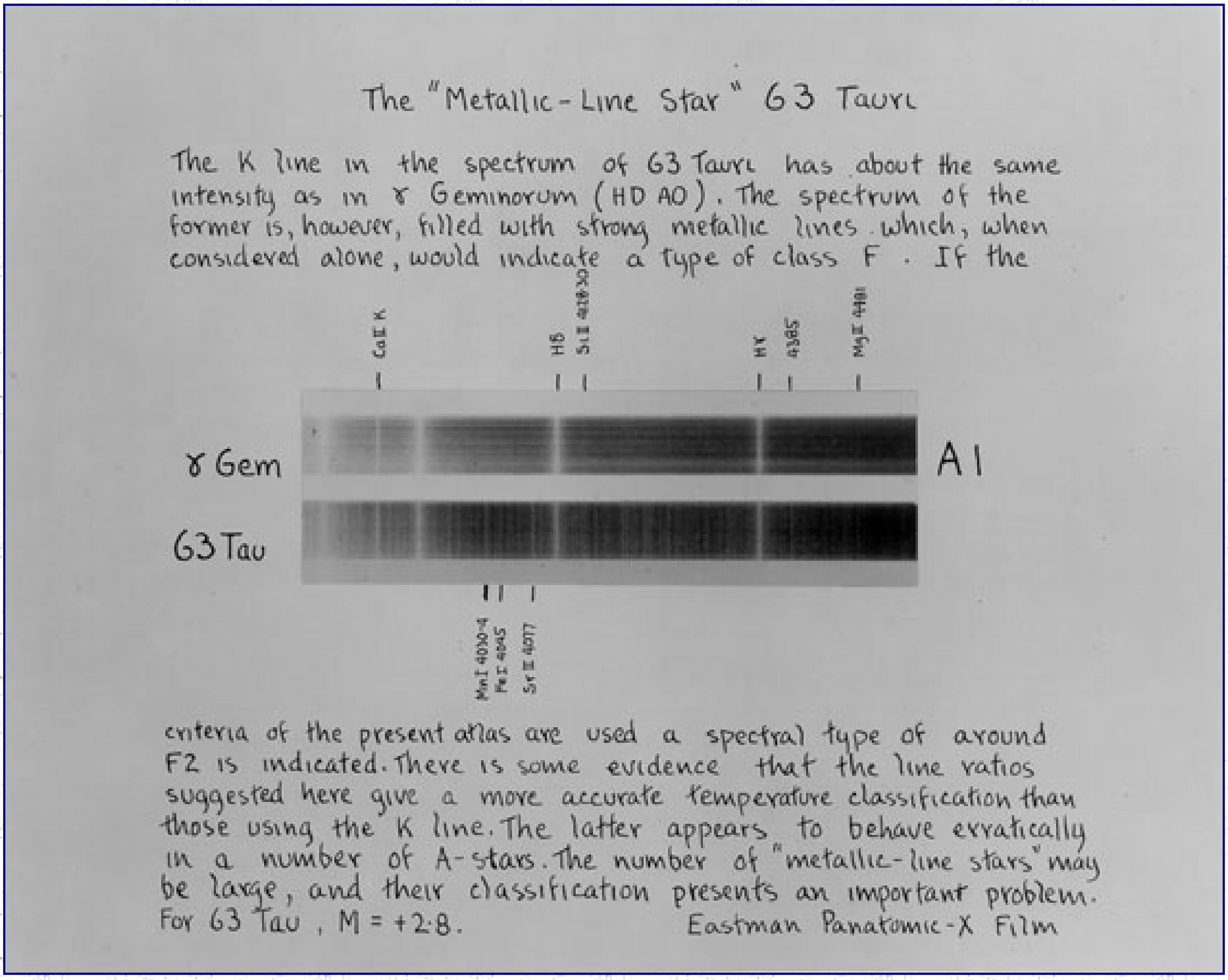

Main Sequence A2-F0
The blends at λλ 4030-4 and 4300 increase rapidly in intensity from A2 to F0
4128-32
4272 4300
4385
Mg II 4481
ζ UMa br.
β Ari
α Aql
γ Vir
A2
A5
A7
F0
Mn I 4030-4
Fe I 4045
Sr II 4077
4226
4520-35
4549-63
The spectral type is determined from the ratios: Mn I 4030-4 : λ 4128-32, λ 4300 : λ 4385
Eastman Process

Plate 23


The "Metallic-Line Star" 63 Tauri

The K line in the spectrum of 63 Tauri has about the same intensity as in γ Geminorum (HD A0). The spectrum of the former is, however, filled with strong metallic lines which, when considered alone, would indicate a type of class F. If the

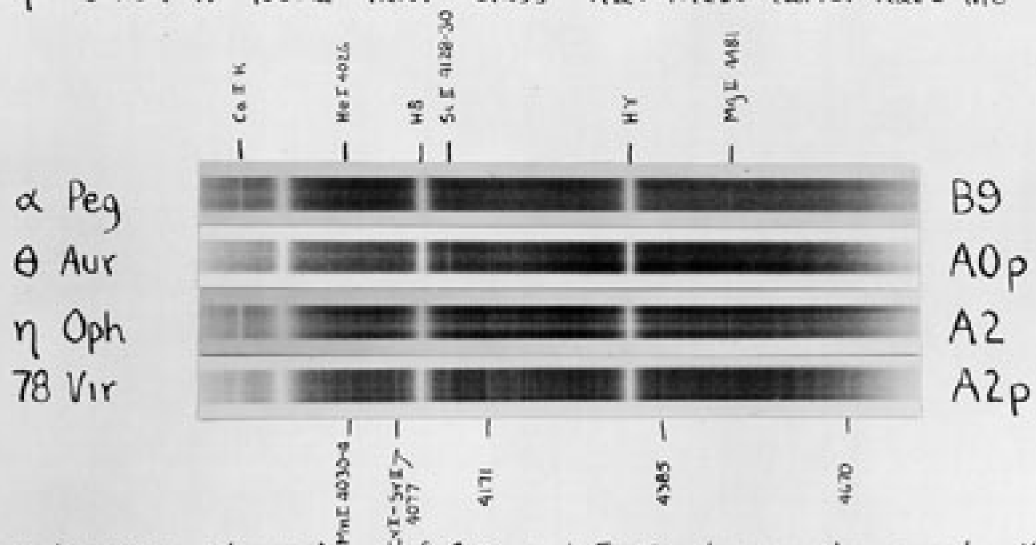
Ca II K
Hδ
Si II 4128-30
Hγ
4385
Mg II 4481
γ Gem
A1
63 Tau
Mn I 4030-4
Fe I 4045
Sr II 4077

criteria of the present atlas are used a spectral type of around F2 is indicated. There is some evidence that the line ratios suggested here give a more accurate temperature classification than those using the K line. The latter appears to behave erratically in a number of A-stars. The number of "metallic-line stars" may be large, and their classification presents an important problem.
For 63 Tau, M = +2.8.
Eastman Panatomic-X Film

Plate 24

Two Peculiar A Stars

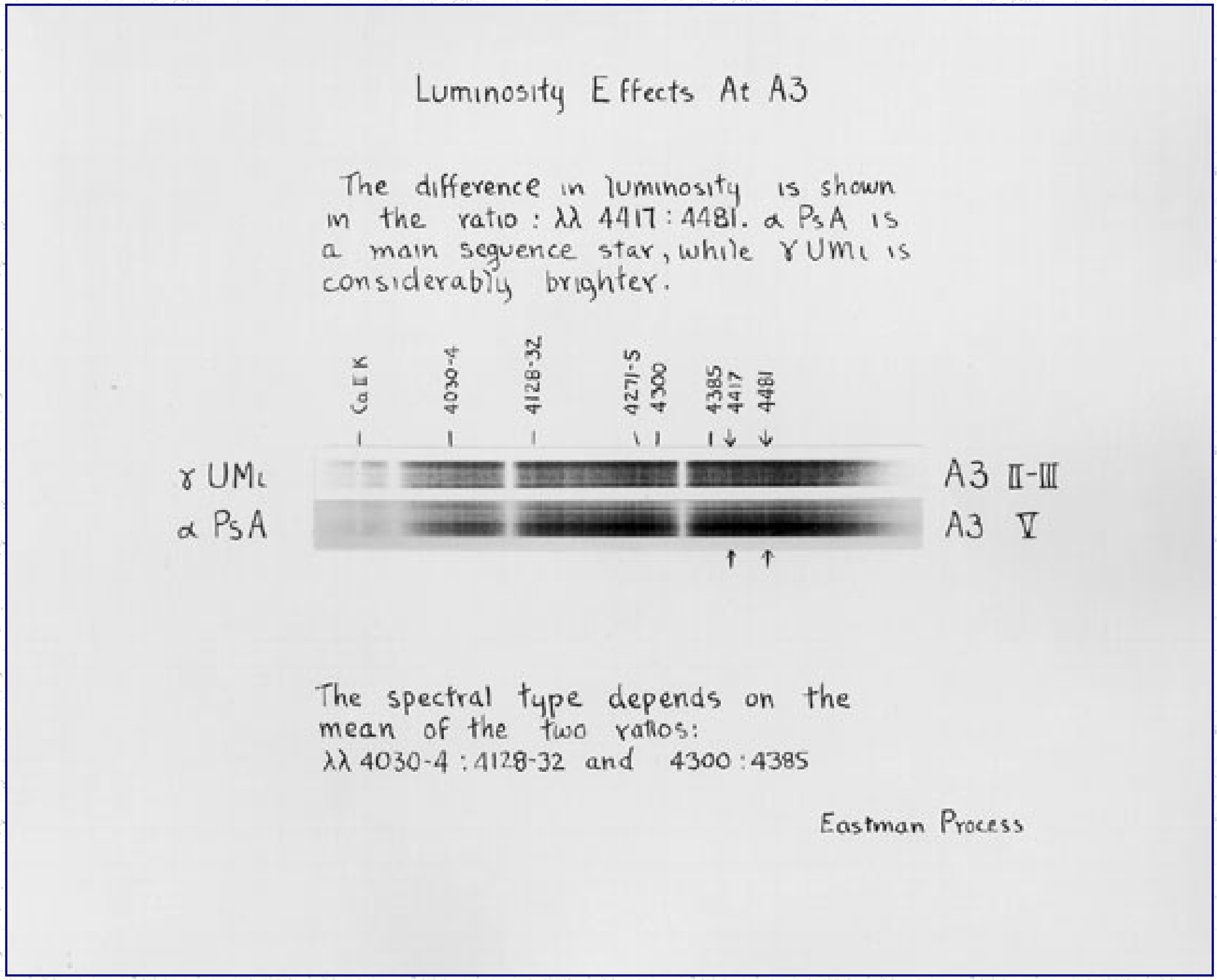
θ Aur is typical of the "silicon stars". The Si II blend at λ 4128-30 is very strong and the K line of Ca II is abnormally weak for the spectral type. The star 78 Vir is a member of the "chromium-europium group" which is found near class A2. These latter have the following



characteristics: strong lines of Cr II and Eu II, abnormally weak K-line and a tendency toward variability in the spectral lines in the case of some of the stars. The Si II lines are weak in general in this class; the strong feature near λ 4130 in 78 Vir is not due principally to Si II. The Sr II lines are strong in certain members. On low dispersion the characteristic feature of this group of stars is the blend near λ 4171; with higher dispersion it is seen to be composed of a number of fainter lines. Eastman Process

Next Contents Previous

Plate 25



Next Contents Previous

Plate 26

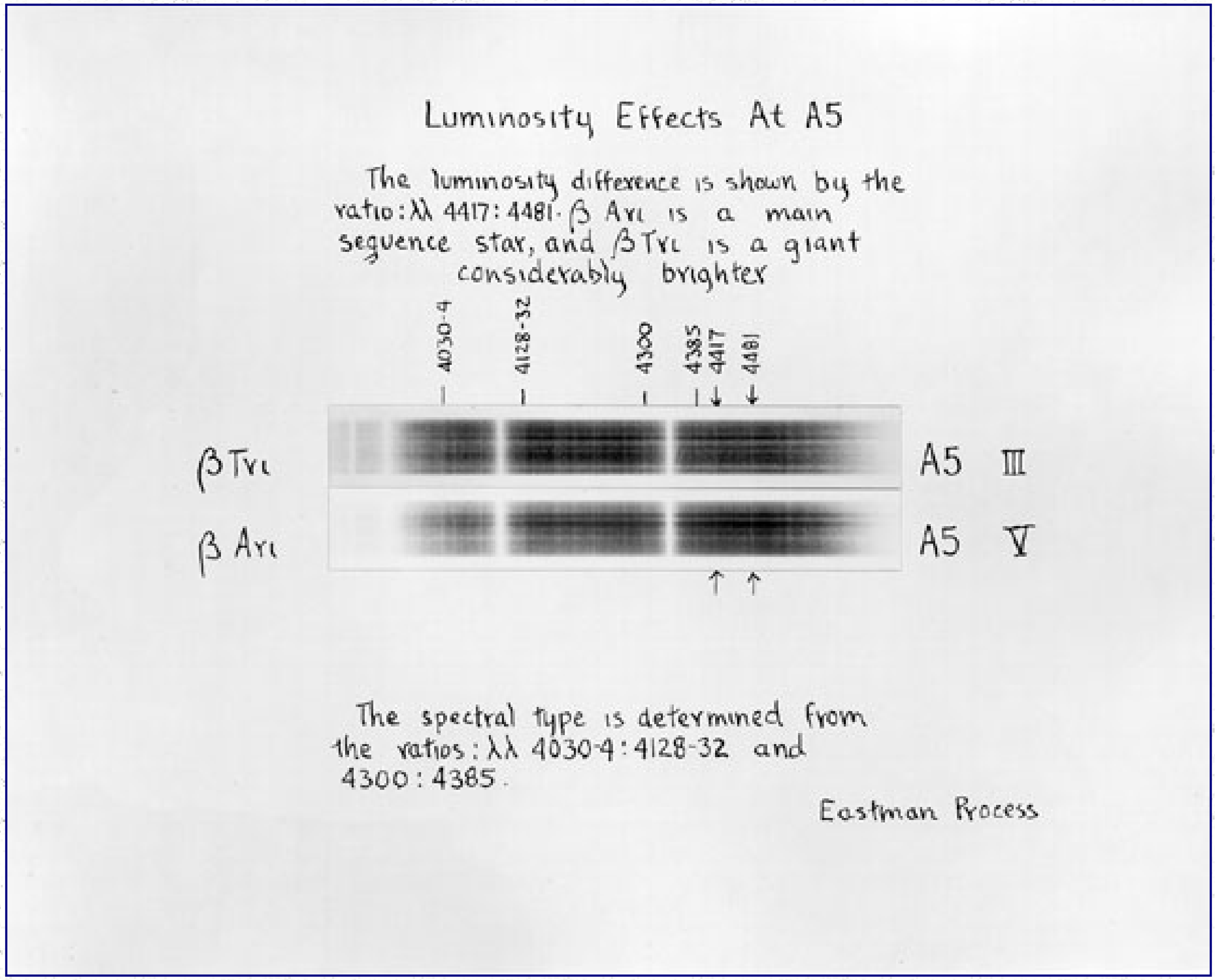
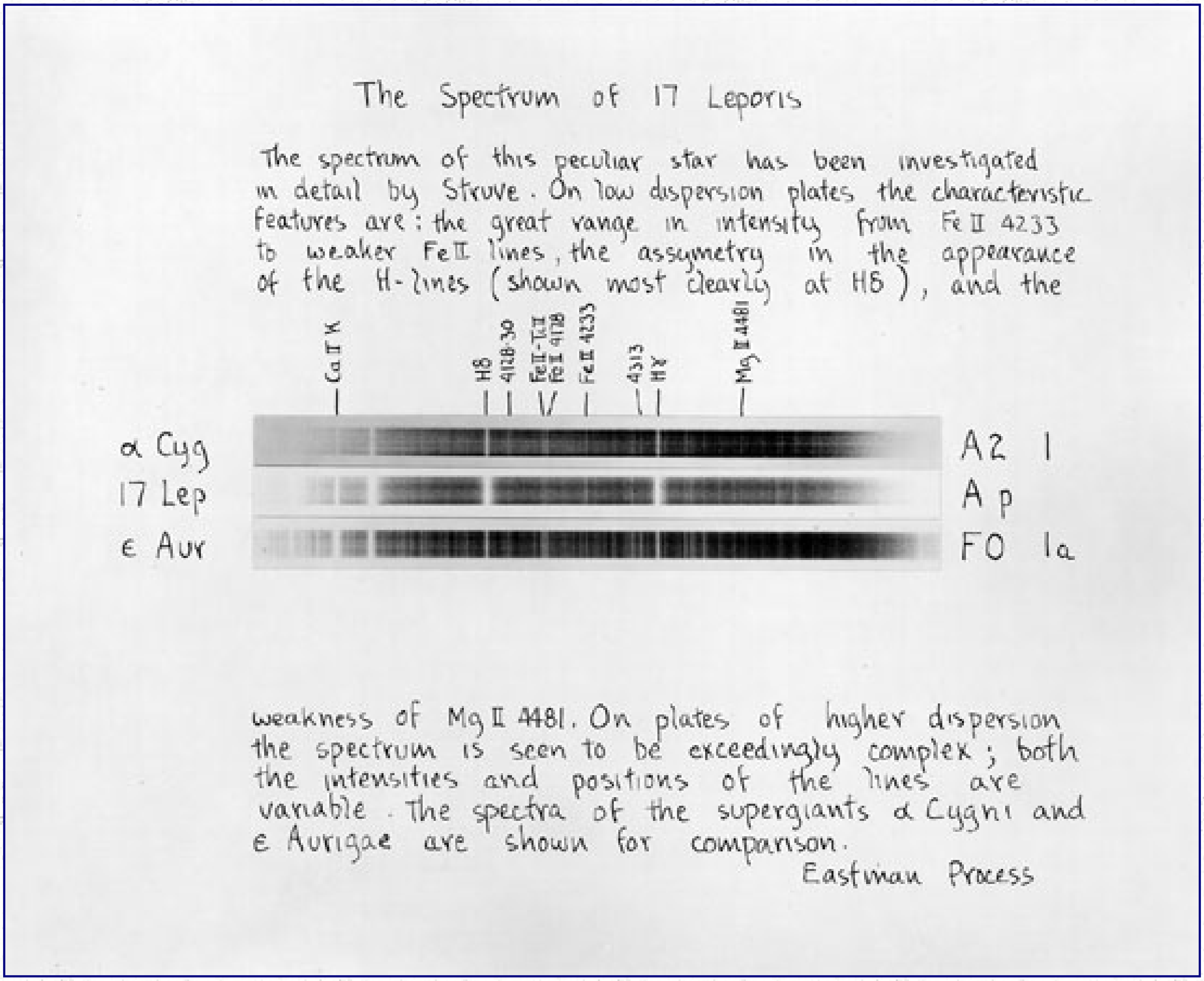


Plate 27


The Spectrum of 17 Leporis
The spectrum of this peculiar star has been investigated in detail by Struve. On low dispersion plates the characteristic features are: the great range in intensity from Fe II 4233 to weaker Fe II lines, the assymetry in the appearance of the H-lines (shown most clearly at Hδ), and the
Ca II K
Hδ
4128-30
Fe II - Ti II
Fe I 4178
Fe II 4233
4313
Hγ
Mg II 4481
α Cyg
17 Lep
ε Aur
A2 I
A p
F0 Ia
weakness of Mg II 4481. On plates of higher dispersion the spectrum is seen to be exceedingly complex; both the intensities and positions of the lines are variable. The spectra of the supergiants α Cygni and ε Aurigae are shown for comparison.
Eastman Process

Next | Contents | Previous

Plate 28

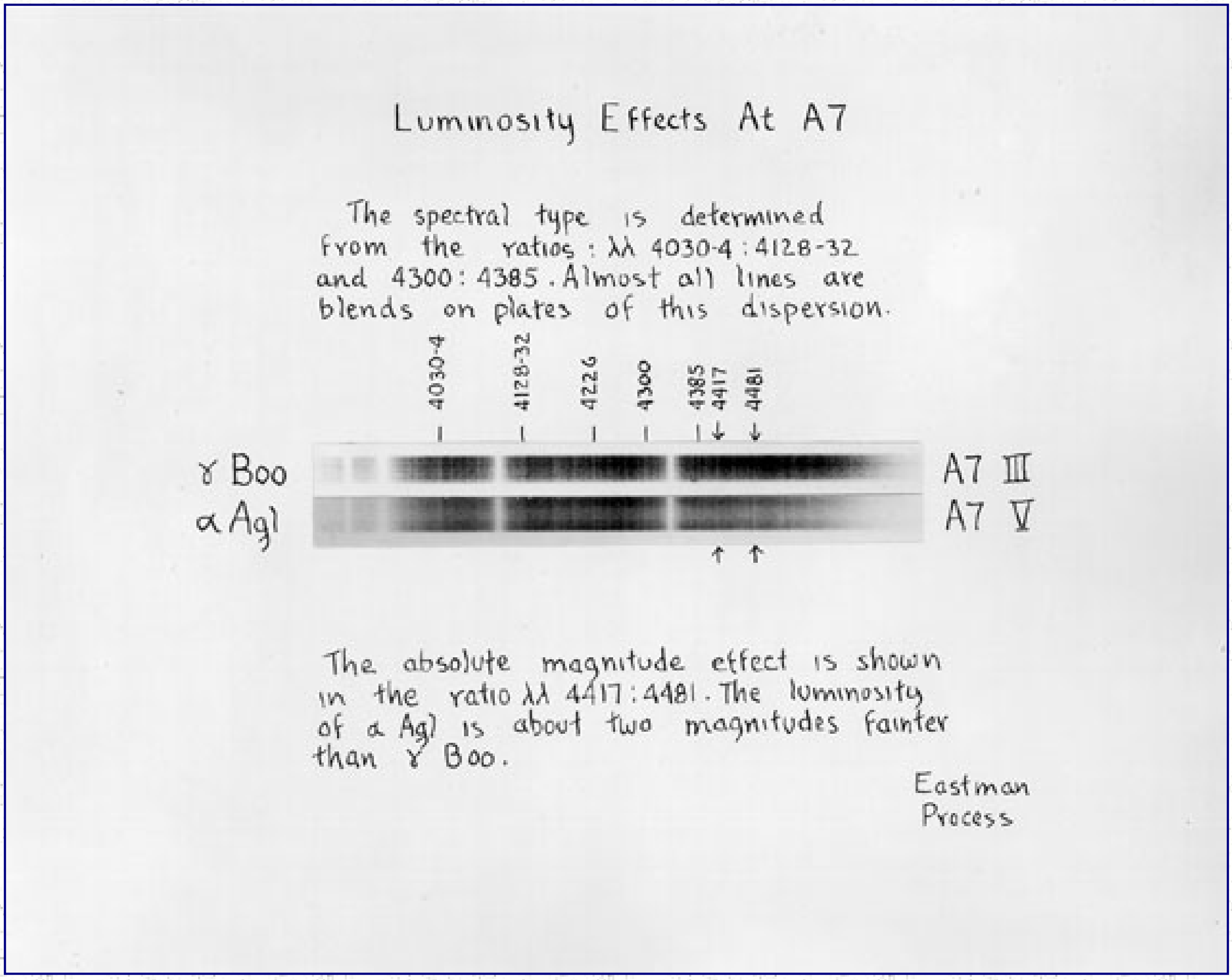
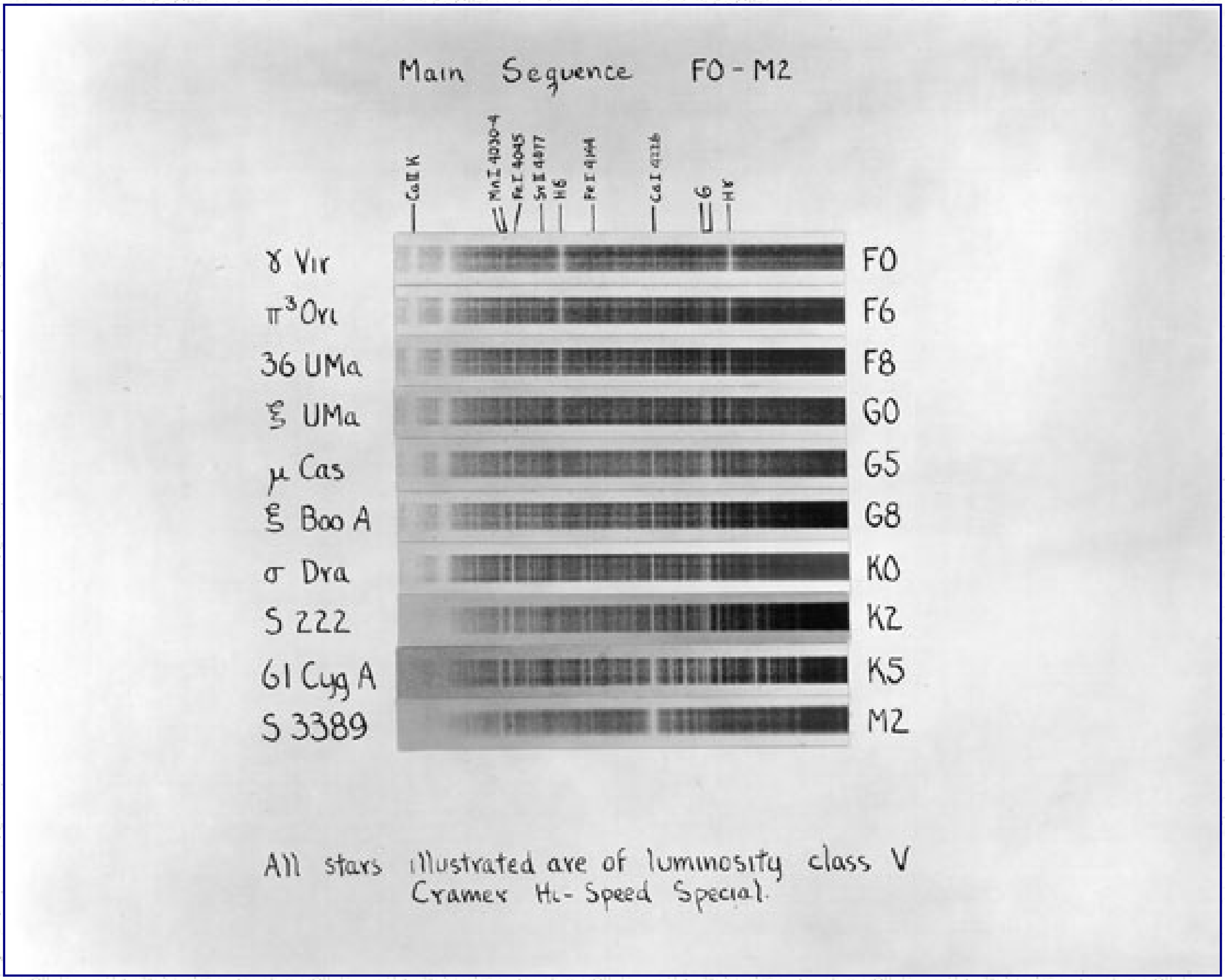


Plate 29


Main Sequence F0 - M2
G
γ Vir F0
π³ Ori F6
36 UMa F8
ξ UMa G0
μ Cas G5
ξ Boo A G8
σ Dra K0
S 222 K2
61 Cyg A K5
S 3389 M2
All stars illustrated are of luminosity class V
Cramer Hi- Speed Special.

Next Contents Previous

Plate 30

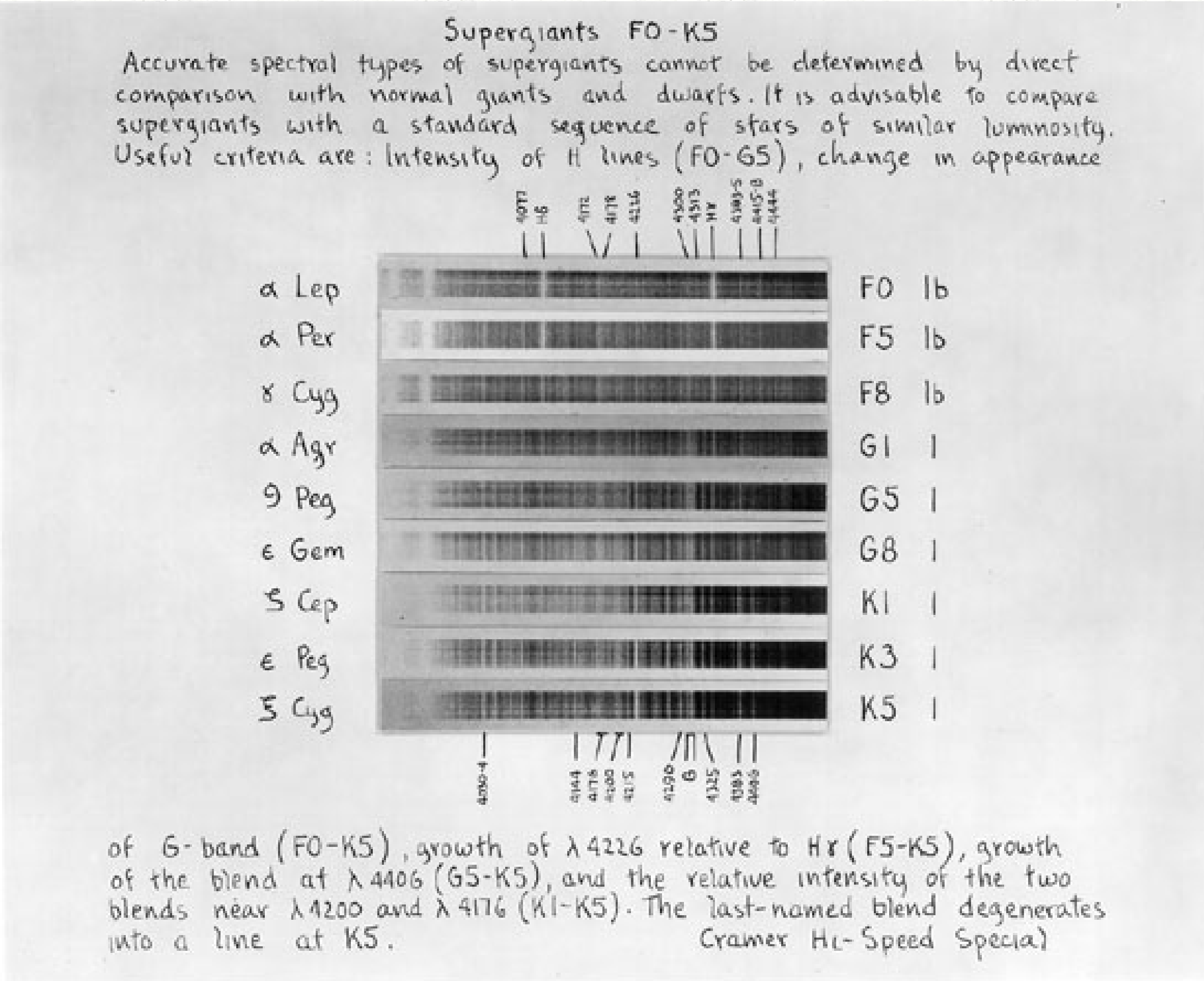


Plate 31

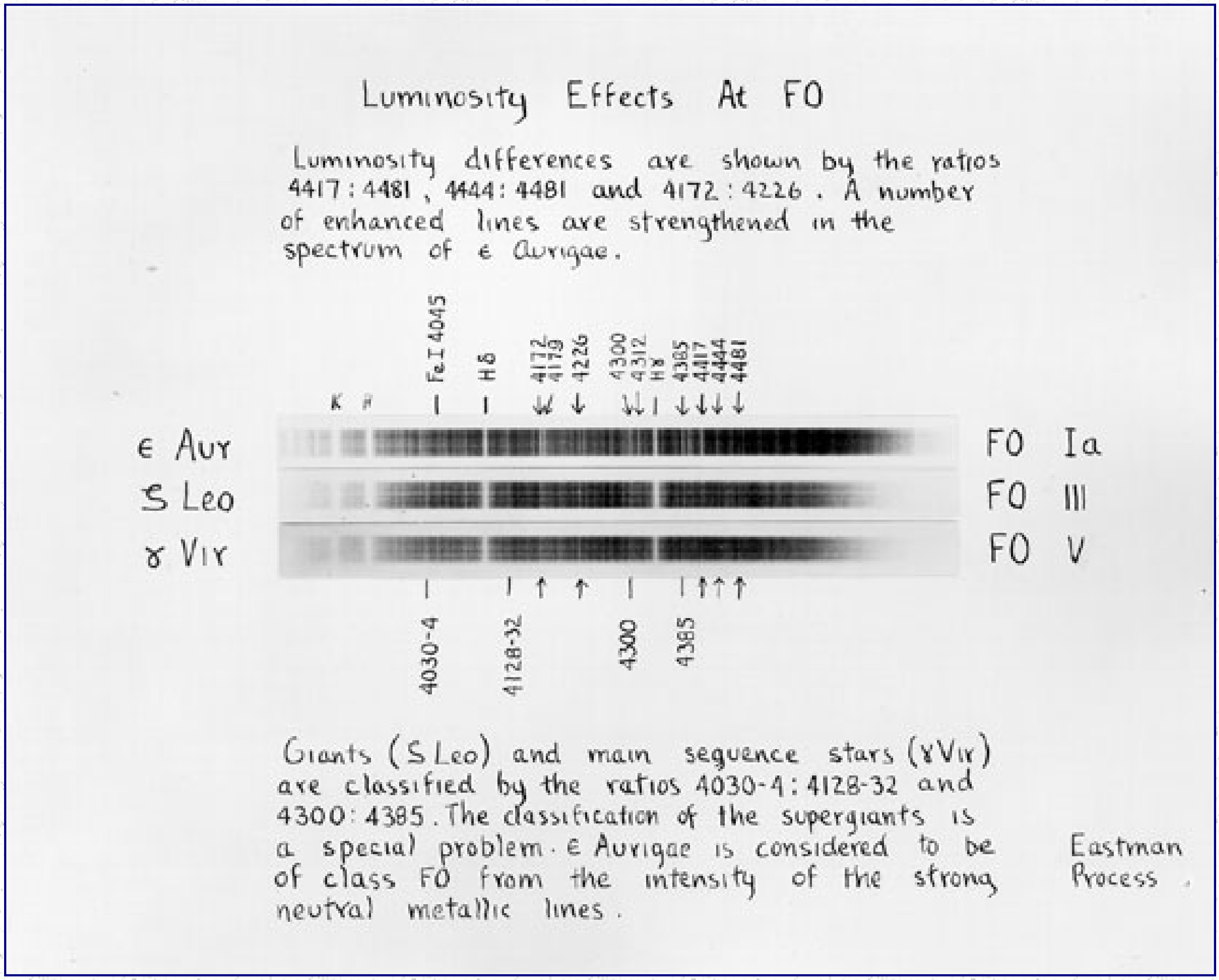
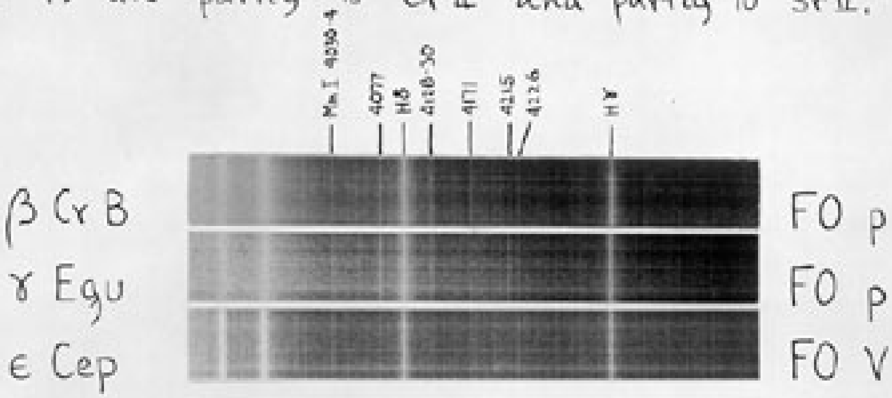

Luminosity Effects At F0
Luminosity differences are shown by the ratios 4417 : 4481 , 4444 : 4481 and 4172 : 4226 . A number of enhanced lines are strengthened in the spectrum of ε Aurigae.
K
H
FeI 4045
Hδ
4172
4179
4226
4300
4312
Hγ
4385
4417
4444
4481
ε Aur
δ Leo
γ Vir
F0 Ia
F0 III
F0 V
4030-4
4128-32
4300
4385
Giants (δ Leo) and main sequence stars (γ Vir) are classified by the ratios 4030-4 : 4128-32 and 4300 : 4385 . The classification of the supergiants is a special problem. ε Aurigae is considered to be of class F0 from the intensity of the strong neutral metallic lines.
Eastman Process

Plate 32

The Peculiar F Stars β CrB and γ Equ

β CrB is a "chromium-europium star". On plates of higher dispersion Eu II is seen to be well-marked. The blend near λ 4171, which appears to be characteristic of the "chromium stars", is strong. The blend at λ4128-30 is not due principally to Si II. The line at λ 4077 is due partly to Cr II and partly to Sr II.



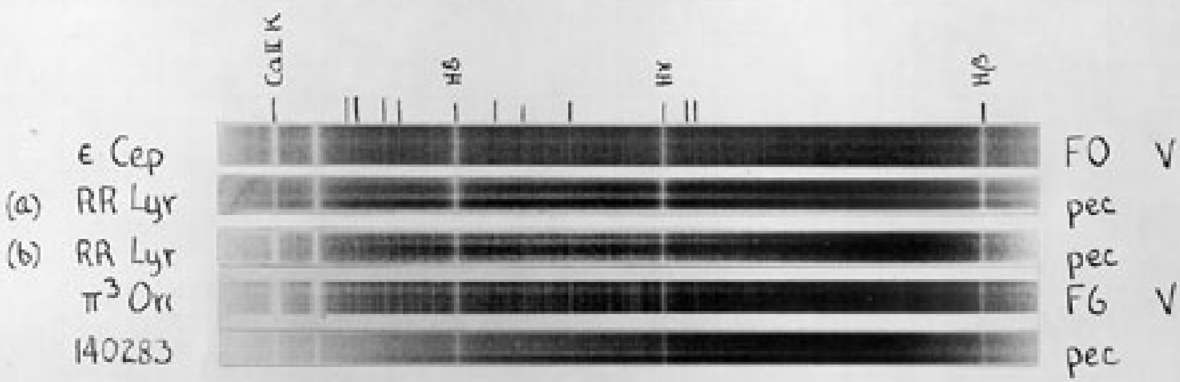
γ Equ is a "strontium star". The lines at λλ 4077 and 4215 of Sr II are outstanding in strength. On plates of higher dispersion it is seen that Eu II is also strong. The blend at λ 4128-30 is not due principally to Si II. The strength of this blend in the spectra of stars later than type A0 seems to be indicative of the presence of Eu II. A comparison with the plate showing luminosity effects at F0 indicates that the spectral peculiarities of γ Equ and β CrB cannot be interpreted as simple absolute magnitude effects.

Cramer Hi-Speed Special

Plate 33

The Cluster Type Variable RR Lyr

The spectrum of RR Lyr is peculiar and cannot be located accurately in a spectral classification system. The intensity of the H lines is similar to the normal dwarf ε Cep (F0) at the phase when spectrogram (a) was taken. The numerous

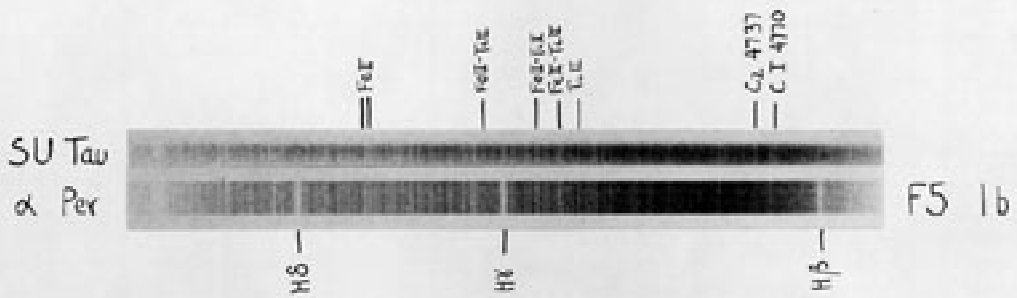


metallic lines present in the spectrum of ε Cep are faint or invisible on plate (a). At the same time, the K line has an intensity similar to an early A star. At the phase when plate (b) was taken the H lines have become weaker and the K line stronger. The H lines are similar to π^3 Ori (F6), while the metallic lines are about as strong as in class F0. Spectrum (a) bears a resemblance to the high-velocity dwarf HD 140283. Cramer Hi-Speed Special

Plate 34

The Variable Star SU Tau

The light variations of SU Tau are similar to those of R CrB and RY Sgr. All three stars have spectra similar in the following respects: the hydrogen lines are exceedingly weak; the singly ionized metallic lines are similar in strength to an F5 supergiant; the C_2 band at λ 4737 is faintly



present, and the lines of C I in the neighborhood of λ 4770 are seen as a broad blend on spectrograms of low dispersion. The plate of SU Tau was taken on Sept 25, 1940. The magnitude of the variable was about 9.7

Cramer Hi-Speed Special

Plate 35

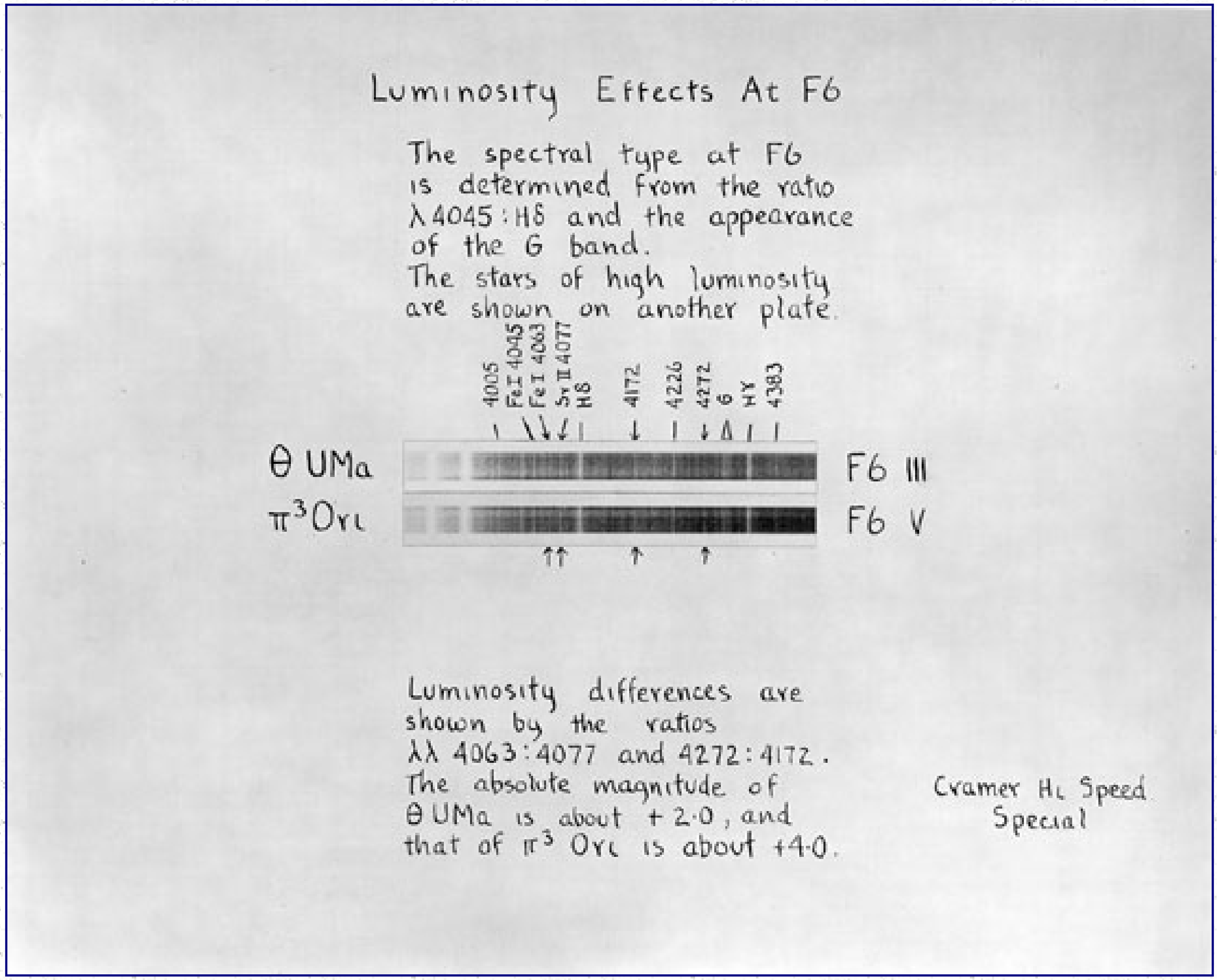

Luminosity Effects At F6
The spectral type at F6
is determined from the ratio
λ4045 : Hδ and the appearance
of the G band.
The stars of high luminosity
are shown on another plate.
4005
FeI 4045
FeI 4063
SrII 4077
Hδ
4172
4226
4272
G
Hγ
4383
θ UMa
π3 Ori
F6 III
F6 V
Luminosity differences are
shown by the ratios
λλ 4063 : 4077 and 4272 : 4172.
The absolute magnitude of
θ UMa is about + 2.0, and
that of π3 Ori is about +4.0.
Cramer Hi Speed
Special

Plate 36

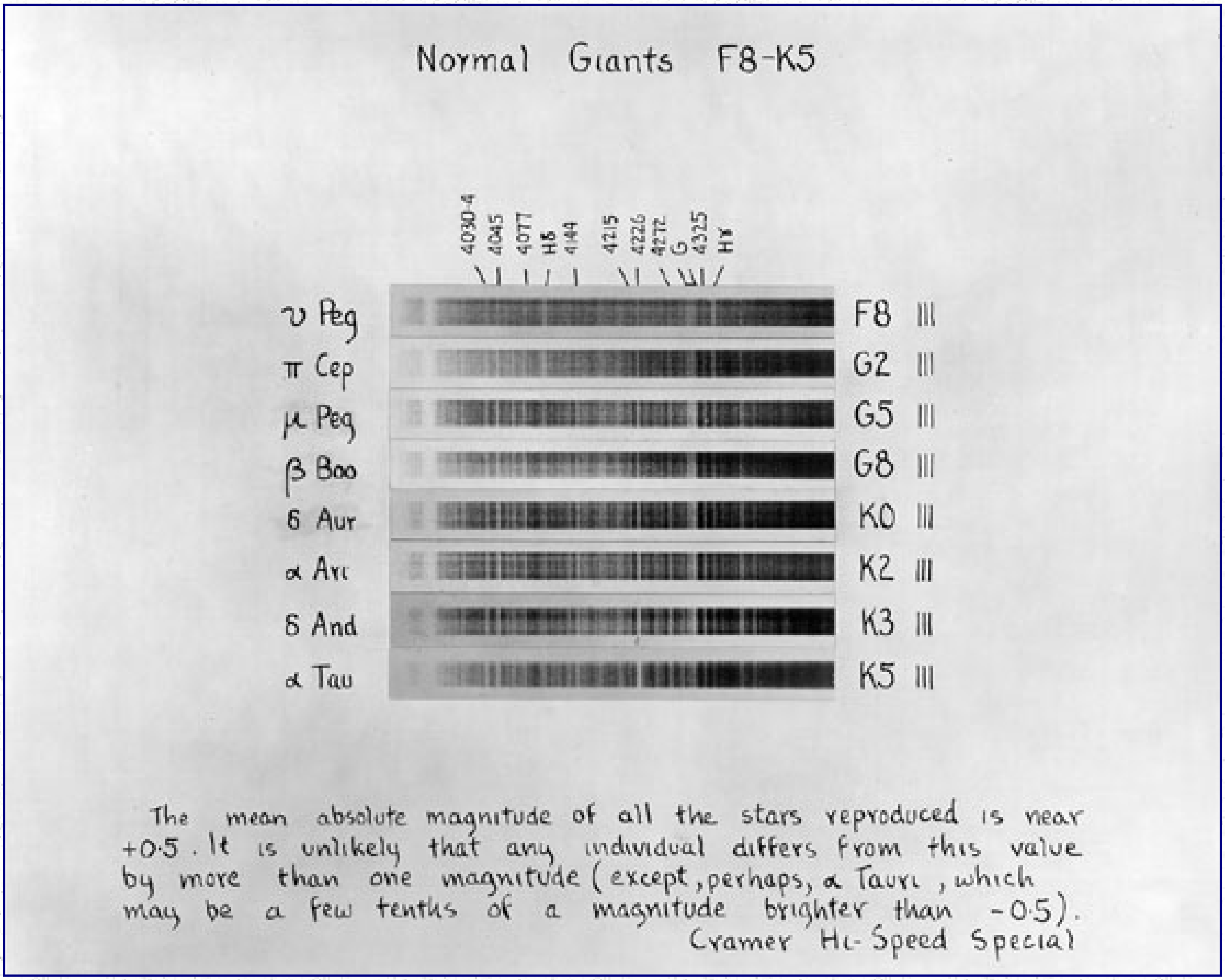

Normal Giants F8-K5
4030-4
4045
4077
Hδ
4144
4215
4226
4272
G
4325
Hγ
υ Peg F8 III
π Cep G2 III
μ Peg G5 III
β Boo G8 III
δ Aur K0 III
α Arc K2 III
δ And K3 III
α Tau K5 III
The mean absolute magnitude of all the stars reproduced is near +0.5. It is unlikely that any individual differs from this value by more than one magnitude (except, perhaps, α Tauri, which may be a few tenths of a magnitude brighter than -0.5).
Cramer Hi-Speed Special

Plate 37

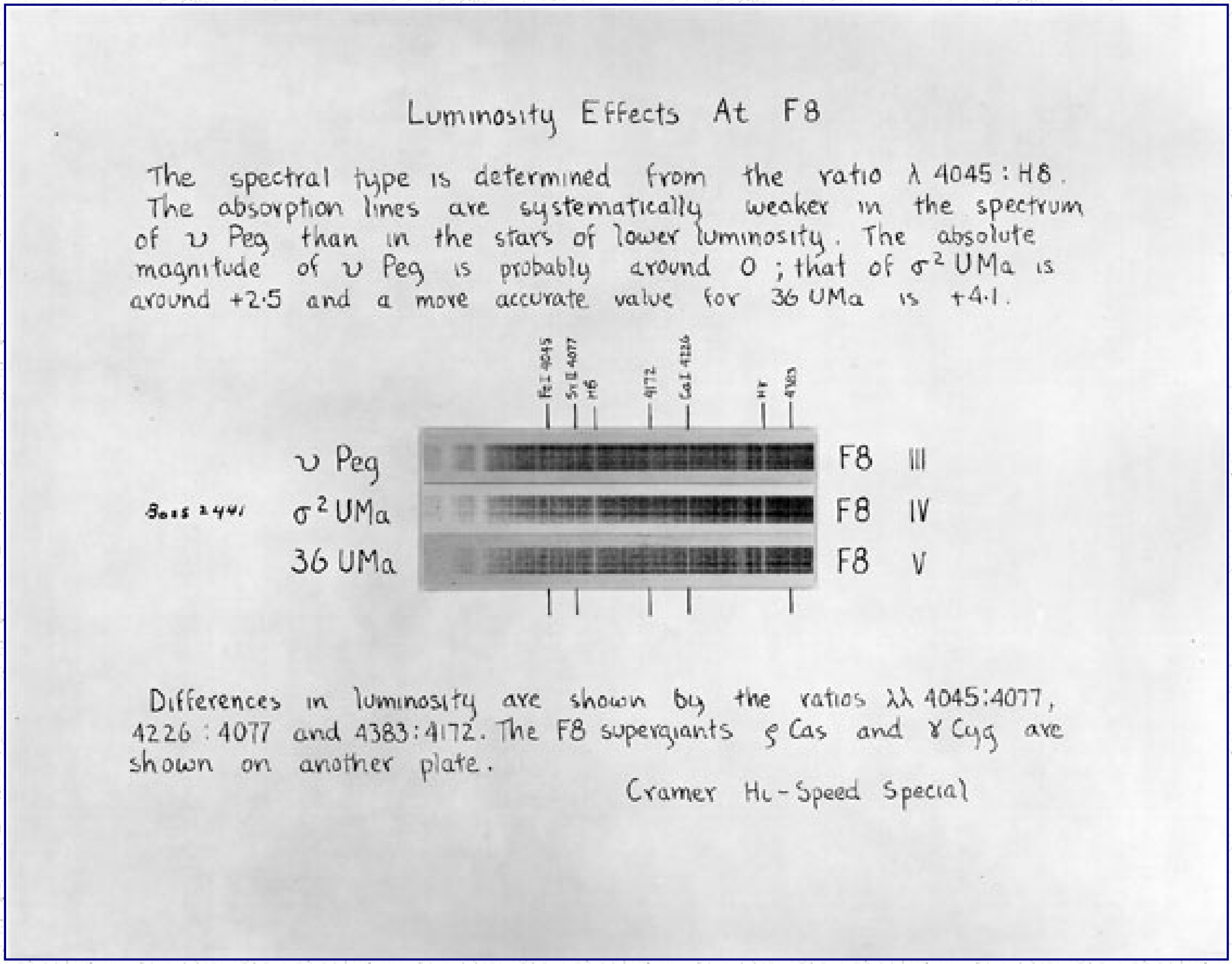

Luminosity Effects At F8
The spectral type is determined from the ratio λ 4045 : Hδ. The absorption lines are systematically weaker in the spectrum of υ Peg than in the stars of lower luminosity. The absolute magnitude of υ Peg is probably around 0 ; that of σ² UMa is around +2·5 and a more accurate value for 36 UMa is +4·1.
FeI 4045
SrII 4077
Hδ
4172
CaI 4226
Hγ
4383
υ Peg
σ² UMa
36 UMa
F8 III
F8 IV
F8 V
Differences in luminosity are shown by the ratios λλ 4045:4077, 4226 : 4077 and 4383:4172. The F8 supergiants ρ Cas and γ Cyg are shown on another plate.
Cramer Hi-Speed Special

Plate 38

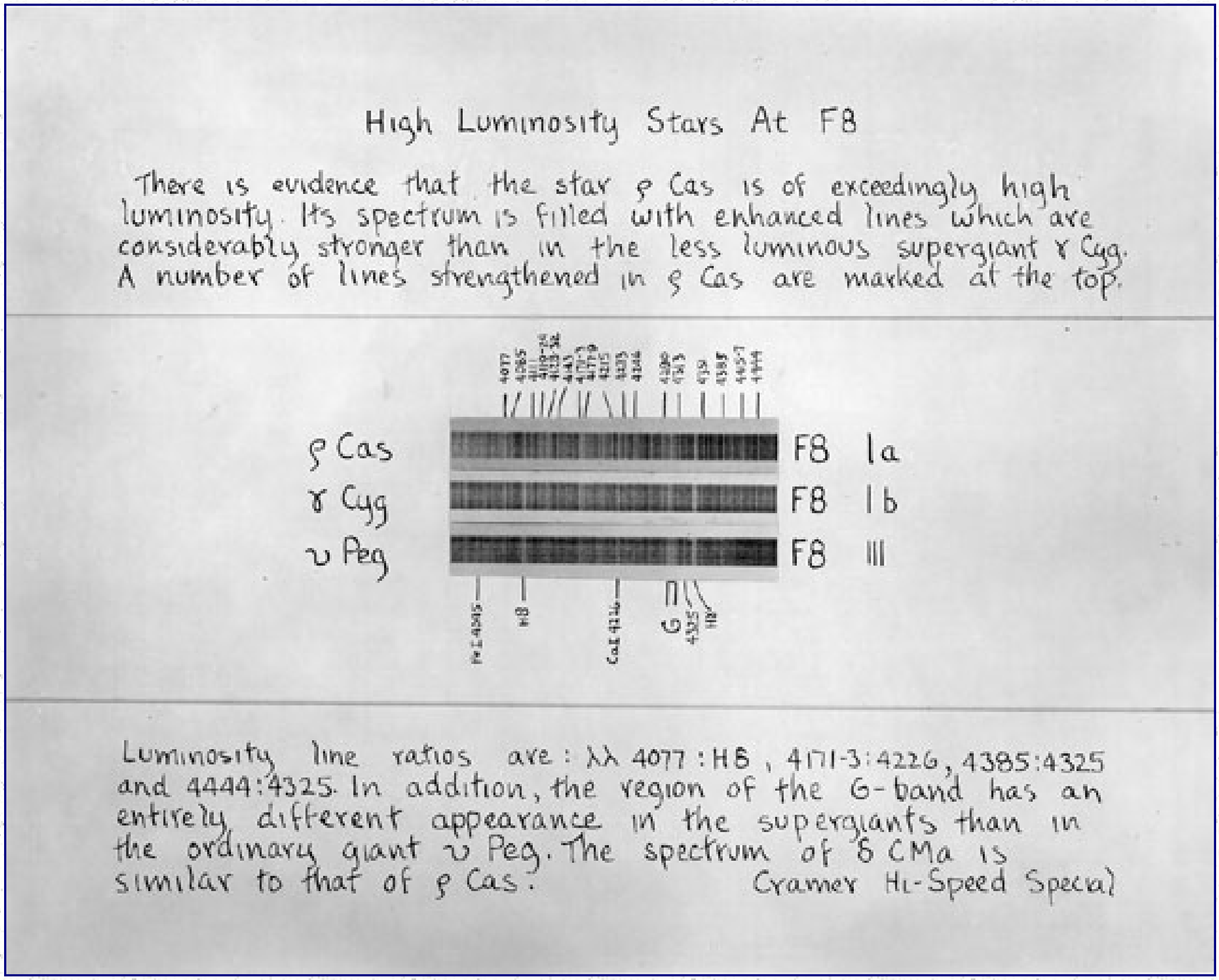

High Luminosity Stars At F8
There is evidence that the star ρ Cas is of exceedingly high luminosity. Its spectrum is filled with enhanced lines which are considerably stronger than in the less luminous supergiant γ Cyg. A number of lines strengthened in ρ Cas are marked at the top.
ρ Cas
γ Cyg
υ Peg
F8 Ia
F8 Ib
F8 III
Luminosity line ratios are: λλ 4077 : Hδ, 4171-3:4226, 4385:4325 and 4444:4325. In addition, the region of the G-band has an entirely different appearance in the supergiants than in the ordinary giant υ Peg. The spectrum of δ CMa is similar to that of ρ Cas.
Cramer Hi-Speed Special

Plate 39

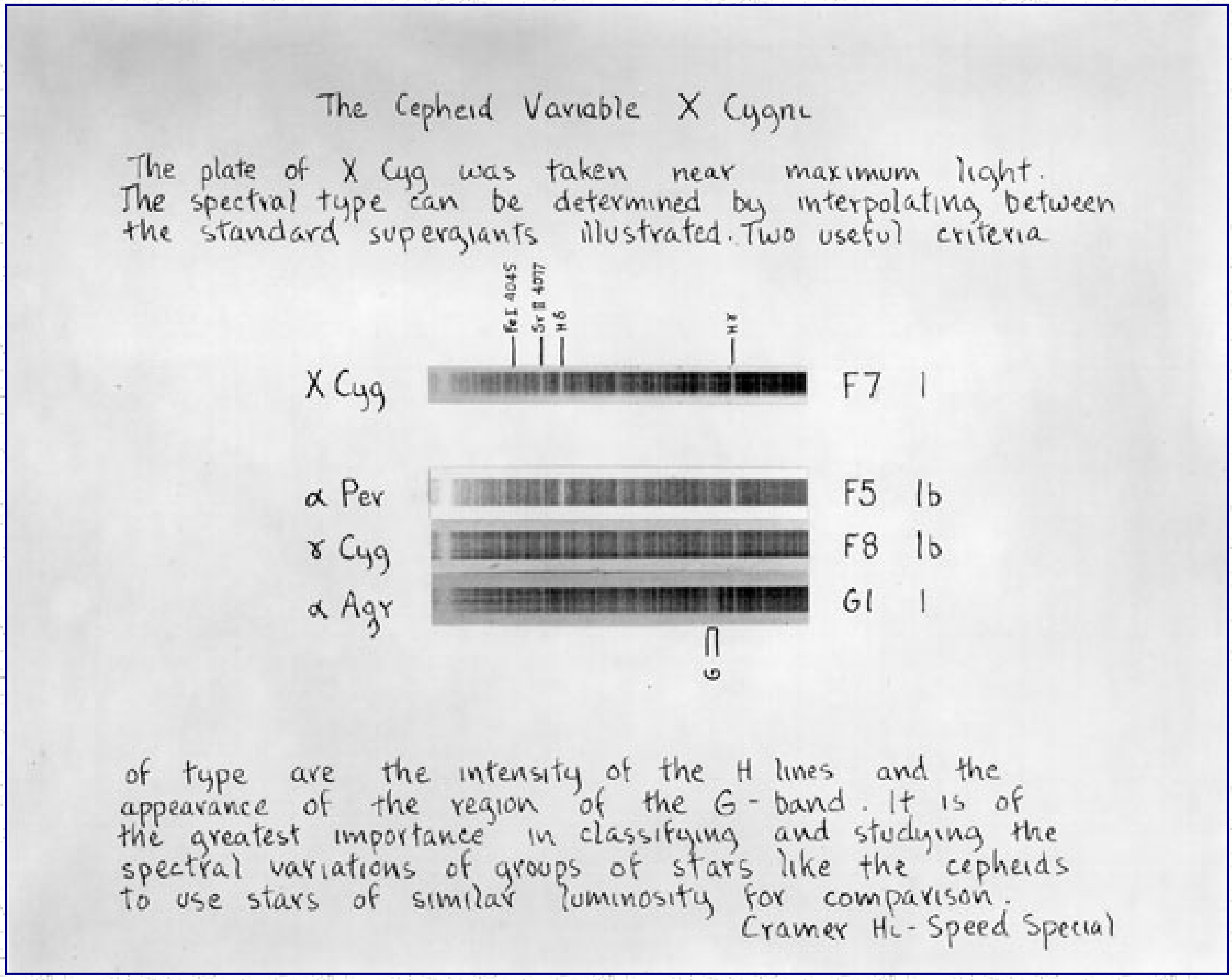
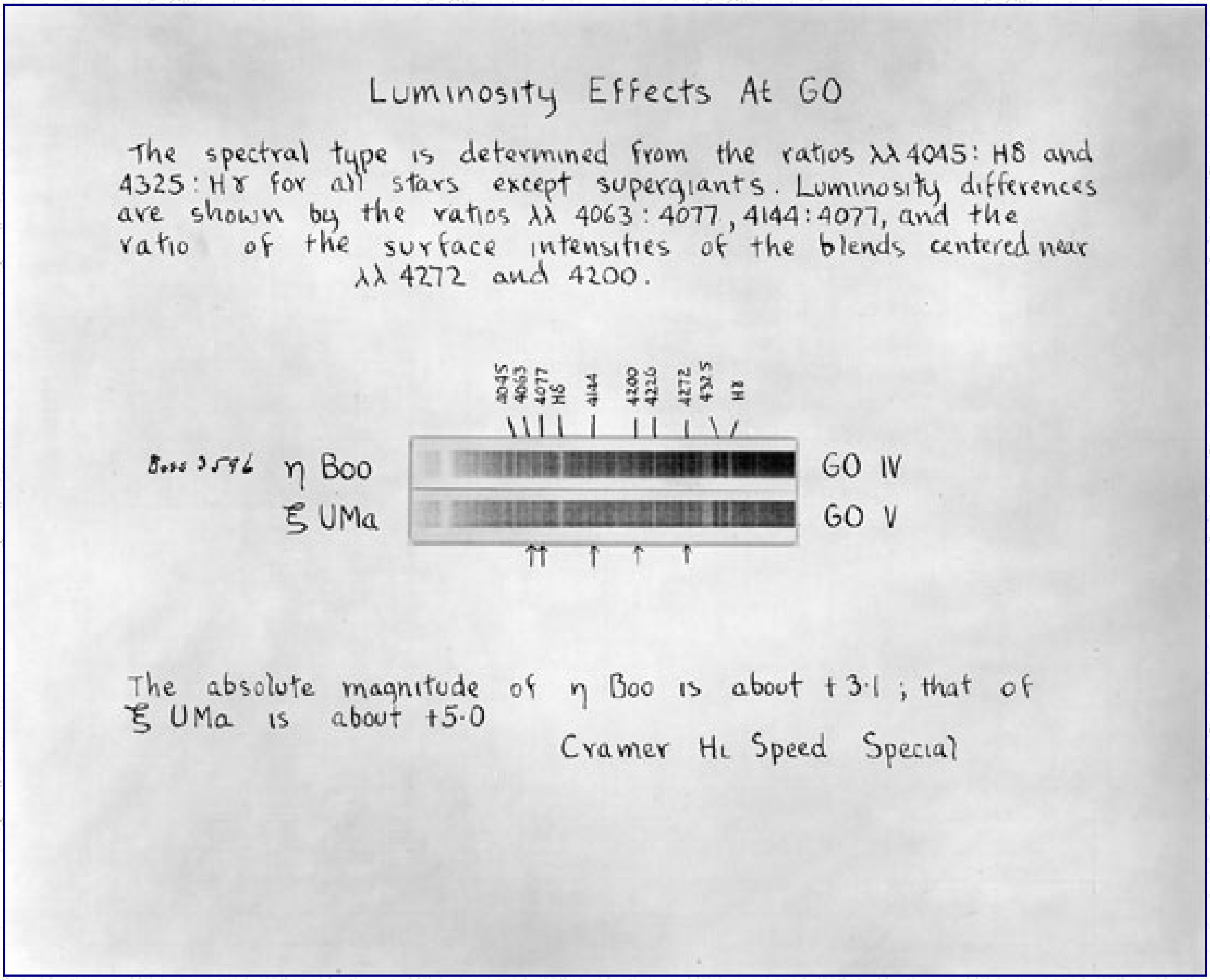

The Cepheid Variable X Cygni
The plate of X Cyg was taken near maximum light. The spectral type can be determined by interpolating between the standard supergiants illustrated. Two useful criteria
FeI 4045
SrII 4077
Hδ
Hγ
X Cyg
F7 I
α Per
F5 Ib
γ Cyg
F8 Ib
α Aqr
G1 I
G
of type are the intensity of the H lines and the appearance of the region of the G-band. It is of the greatest importance in classifying and studying the spectral variations of groups of stars like the cepheids to use stars of similar luminosity for comparison.
Cramer Hi-Speed Special

Plate 40

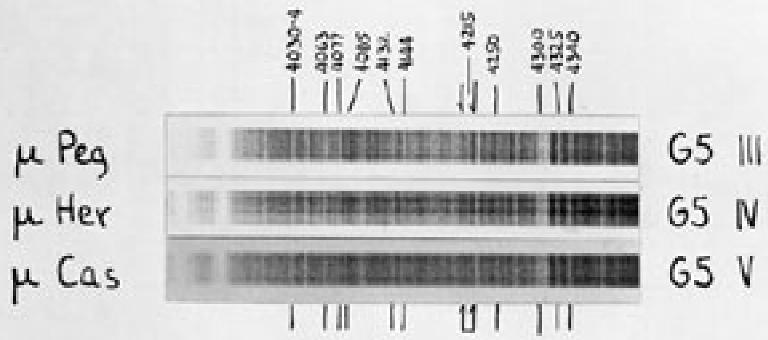

Luminosity Effects At G0
The spectral type is determined from the ratios λλ 4045 : Hδ and 4325 : Hγ for all stars except supergiants. Luminosity differences are shown by the ratios λλ 4063 : 4077, 4144 : 4077, and the ratio of the surface intensities of the blends centered near λλ 4272 and 4200.
4045
4063
4077
Hδ
4144
4200
4226
4272
4325
Hγ
η Boo
ξ UMa
G0 IV
G0 V
The absolute magnitude of η Boo is about +3·1 ; that of ξ UMa is about +5·0
Cramer Hi Speed Special

Next Contents Previous

Plate 41

Luminosity Effects At G5

The spectral type at G5 is determined by the ratios λλ 4030-4 : 4300 (violet side of G- band) and - with lower weight - λλ 4325 : 4340 Luminosity differences are shown by the ratios λλ 4063:4077 ,4144:4077, 4085:4077 , 4250:4215, and the relative intensity of the continuous spectrum on each side of λ 4215



There is also a change with luminosity in the appearance of the three broad blends between λ 4144 and λ 4215. The broad feature extending toward the violet from λ 4132 undergoes a change in appearance on passing toward lower luminosity and degenerates into a fairly well defined line in μ Cas. The ratio of this line to λ 4077 changes with luminosity. Approximate absolute magnitudes are: μ Peg, +1 ; μ Her, +3.7 ; and μ Cas, +6.1. μ Cas is a high-velocity star.

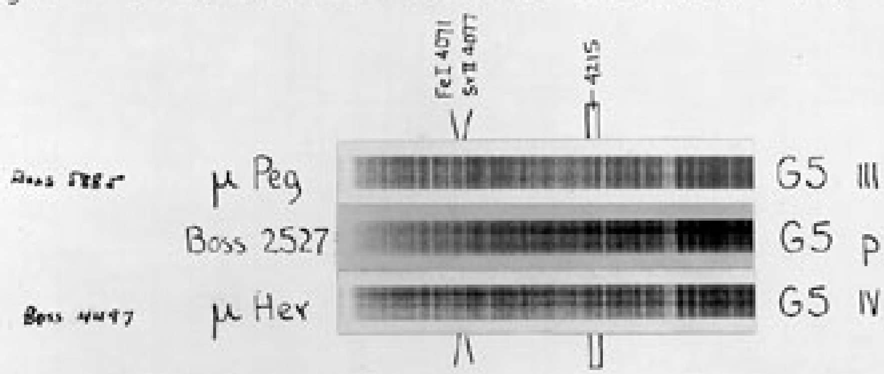
Cramer Hi-Speed Special

Next Contents Previous

Plate 42

The High-Velocity Star Boss 2527

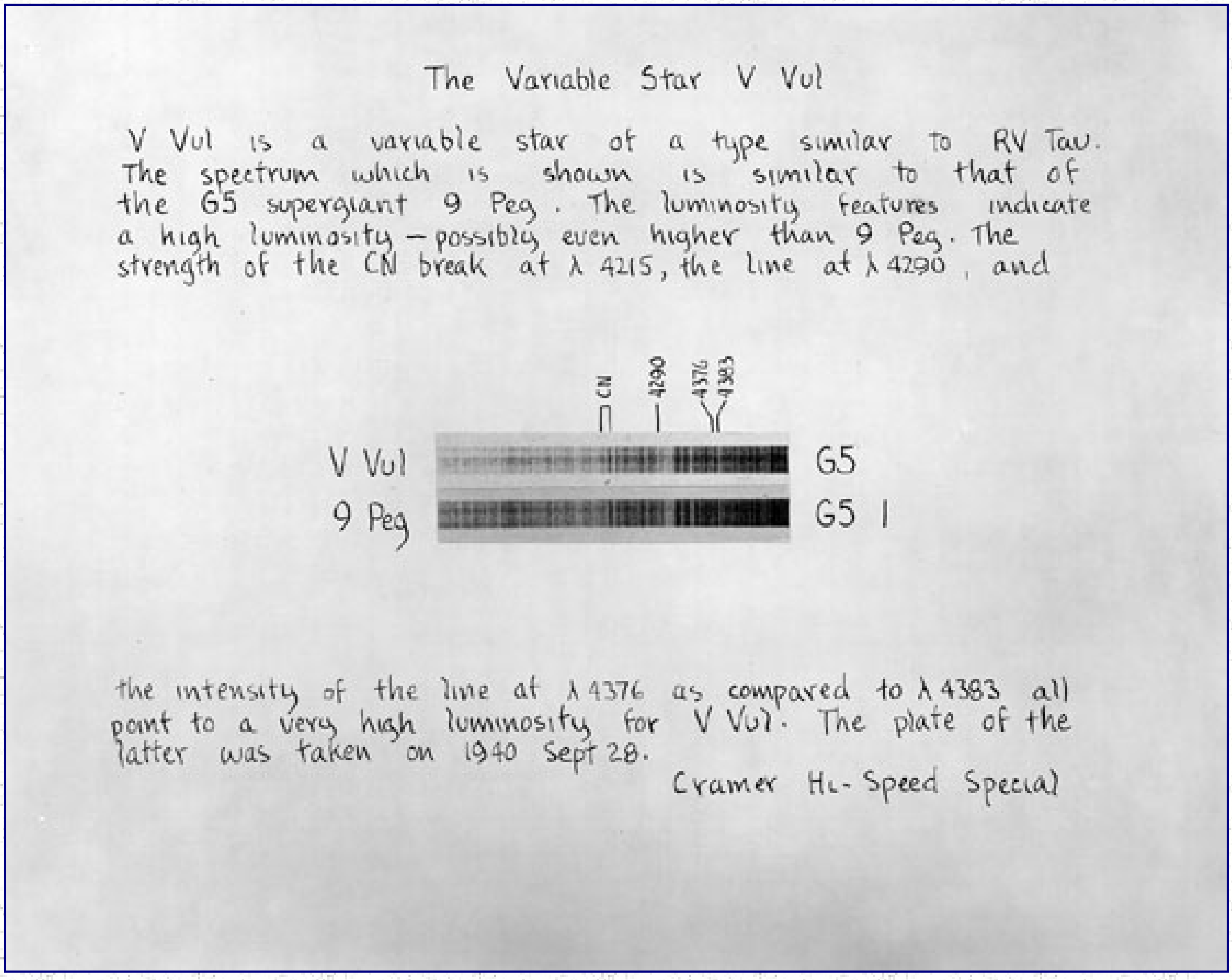
The spectrum of Boss 2527 is similar to that of δ Lep, except that the spectral type is slightly earlier. The radial velocity of Boss 2527 is +136 km/sec. From the weakness of the CN break at λ4215 and the line Sr II 4215 it would be classified as a subgiant or dwarf. On the other hand, the ratio λλ 4077 : 4071



indicates that it is a giant star, similar in luminosity to μ Peg. If analogy to δ Lep is considered justified the parallax of Boss 2527 is found to be around 0.″007. High-velocity stars like Boss 2527, δ Lep and α Boo appear to be the only stars likely to cause serious trouble in using the method of spectroscopic parallaxes. Objects showing more marked peculiarities (such as the R-N stars) are immediately recognizable and can be eliminated.

Next Contents Previous

Plate 43



The Variable Star V Vul

V Vul is a variable star of a type similar to RV Tau. The spectrum which is shown is similar to that of the G5 supergiant 9 Peg. The luminosity features indicate a high luminosity — possibly even higher than 9 Peg. The strength of the CN break at λ 4215, the line at λ 4290, and

the intensity of the line at λ 4376 as compared to λ 4383 all point to a very high luminosity for V Vul. The plate of the latter was taken on 1940 Sept 28.

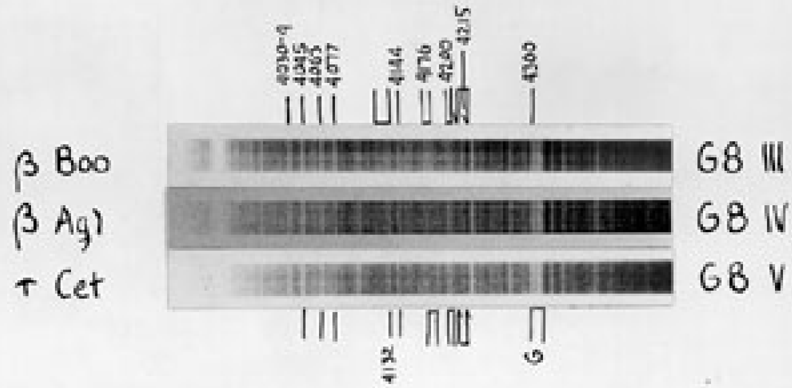
Cramer Hi-Speed Special

Next Contents Previous

Plate 44

Luminosity Effects At G8

The spectral type is determined from the ratio Mn I 4030-4 : λ4300 (violet side of G-band). Differences in luminosity are shown by the ratios λλ 4045 : 4077, 4063 : 4077, 4144 : 4077, and by the difference in the intensity of the continuous spectrum on each side of λ 4215.



Luminosity differences are also shown by the ratio of the surface intensity of the blends near λ 4176 and λ 4200. In addition, there is a marked difference in the appearance of the blend to the violet of λ 4144 on passing from the giant to the dwarf. In the latter the blend degenerates into a line near λ 4132 whose ratio to λ 4077 forms a sensitive discriminant for the separation of subgiants and dwarfs. Approximate absolute magnitudes are: β Boo, 0; β Aql, +3·3; and τ Cet, +6·1.

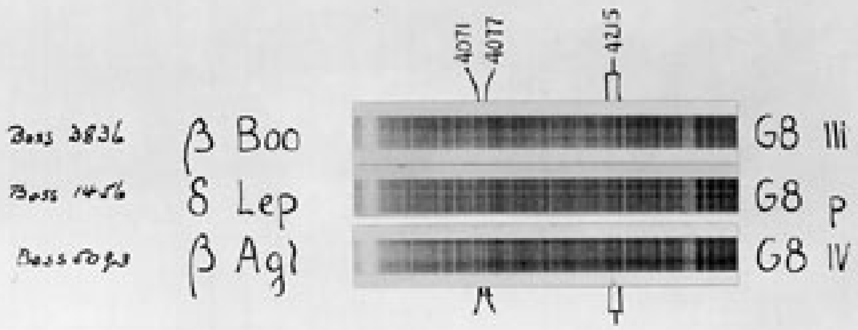
Cramer Hi-Speed Special

Next Contents Previous

Plate 45

The High-Velocity Star δ Leporis

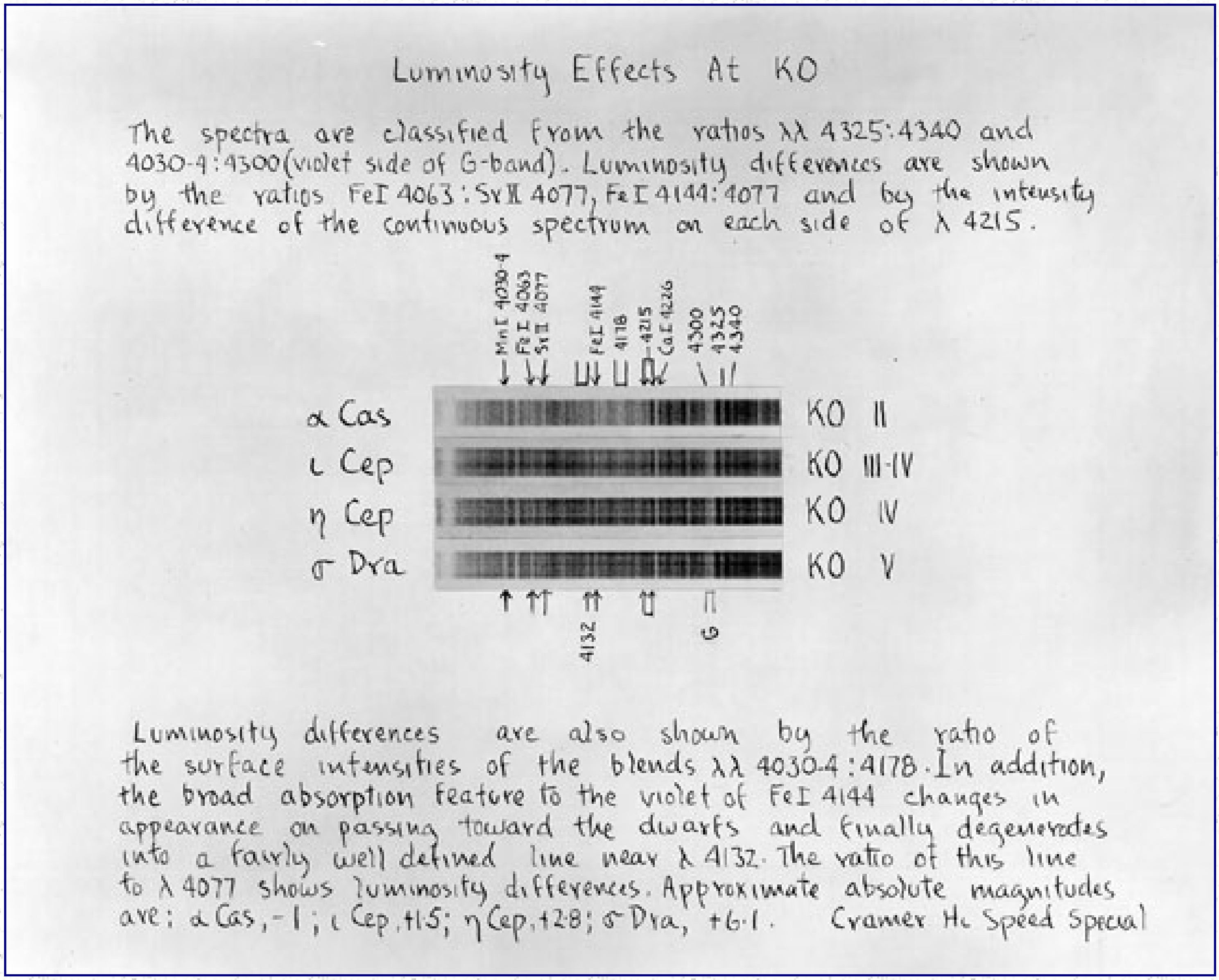
The spectroscopic parallaxes of this star range from 0".132 and 0".096 (Harvard) to 0".079 (Mount Wilson) and 0".030 (Victoria). The trigonometric parallax is of the order of 0".020 or 0".030. The reason for the discrepancy seems to be the conflicting values of the luminosity



criteria. The break at λ 4215 (CN) is no greater than in β Aql and is much less than in the giant β Boo. This would give a parallax of around 0".1. The ratio λ4071:λ4077 indicates a giant, however, and suggests a parallax of around 0".025. Other criteria probably lie between these extremes. This peculiarity occurs in other high-velocity giants of classes G5-K1 and may be a characteristic of the group. The tendency is to make the spectroscopic parallax too great; this is probably the explanation of the long-standing discrepancy in the case of the high-velocity giant α Bootis.

Next Contents Previous

Plate 46



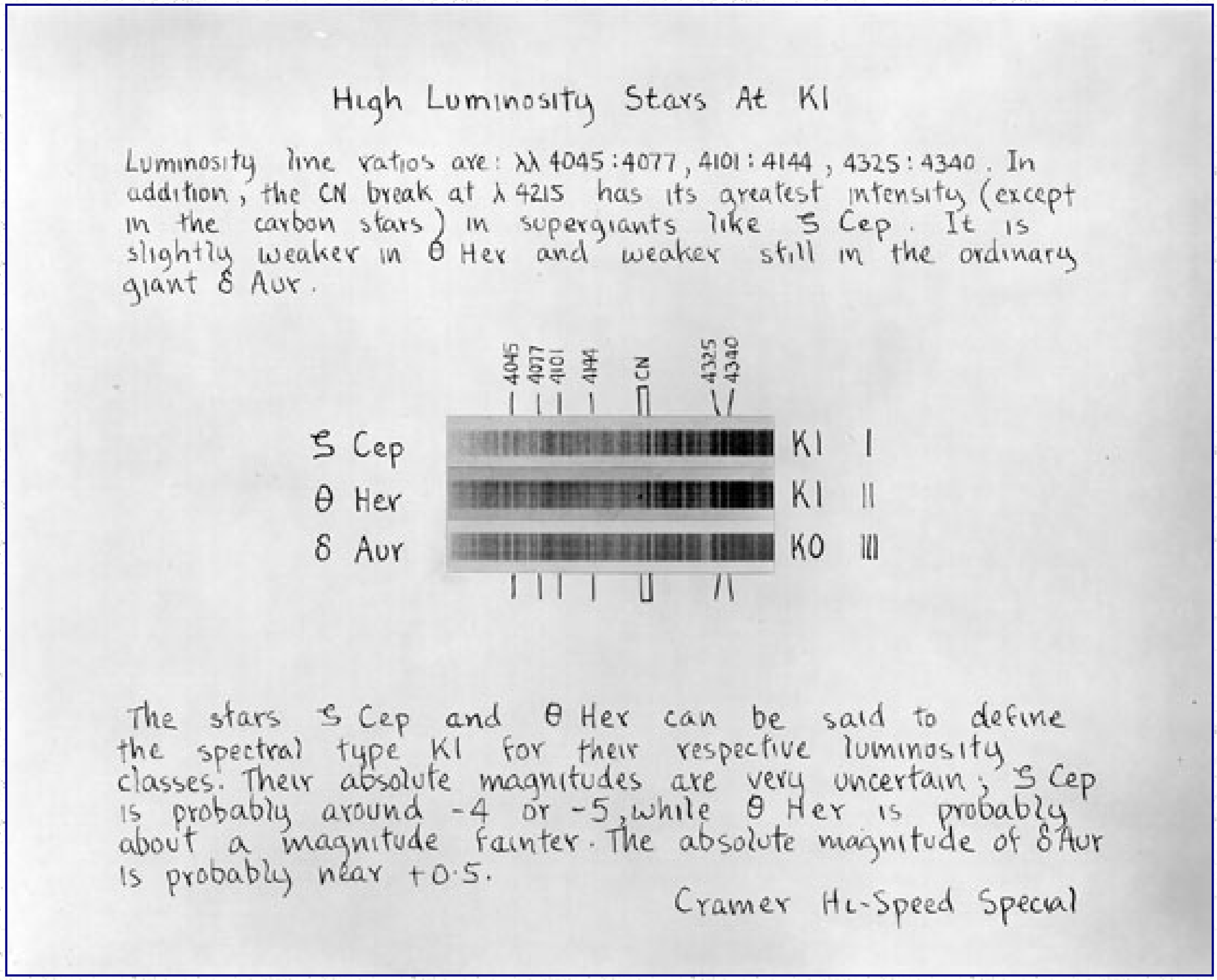
Luminosity Effects At KO

The spectra are classified from the ratios λλ 4325:4340 and 4030-4:4300 (violet side of G-band). Luminosity differences are shown by the ratios FeI 4063:SrII 4077, FeI 4144:4077 and by the intensity difference of the continuous spectrum on each side of λ 4215.

Luminosity differences are also shown by the ratio of the surface intensities of the blends λλ 4030-4:4178. In addition, the broad absorption feature to the violet of FeI 4144 changes in appearance on passing toward the dwarfs and finally degenerates into a fairly well defined line near λ 4132. The ratio of this line to λ 4077 shows luminosity differences. Approximate absolute magnitudes are: α Cas, -1; ι Cep, +1.5; η Cep, +2.8; σ Dra, +6.1. Cramer Hi Speed Special

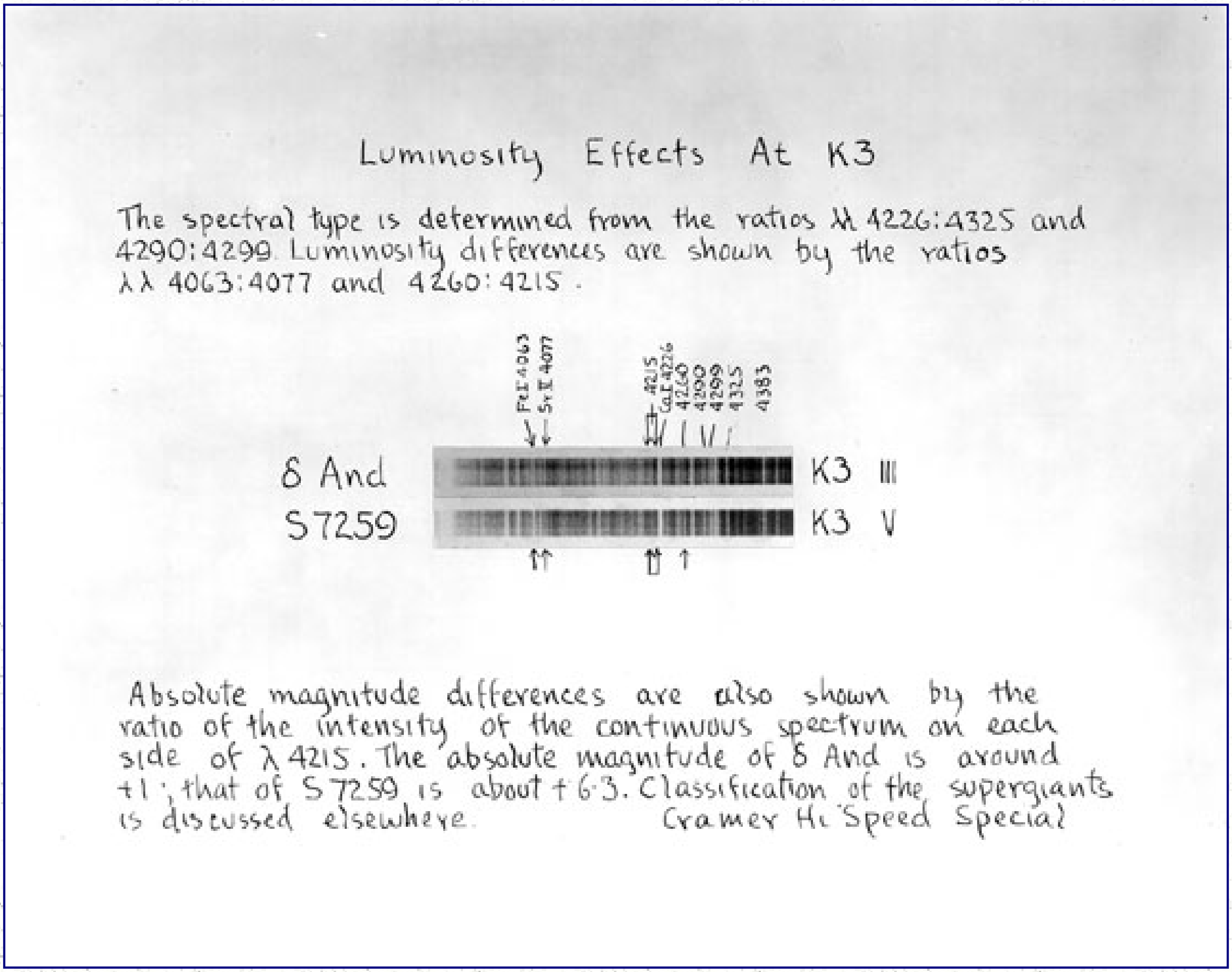
Next Contents Previous

Plate 47



Next Contents Previous

Plate 48

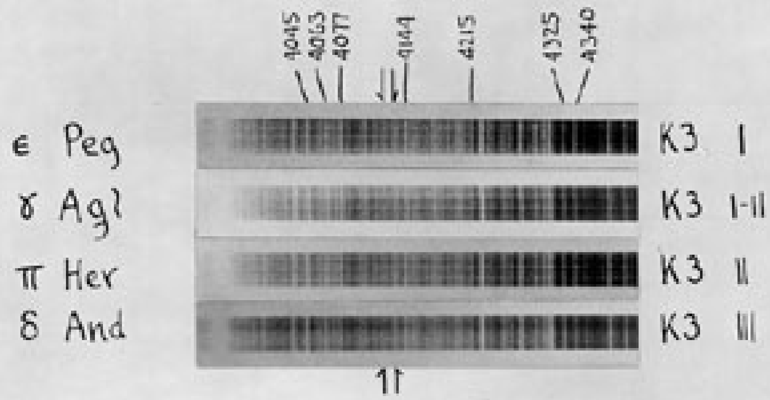


Next Contents Previous

Plate 49

High Luminosity Stars At K3

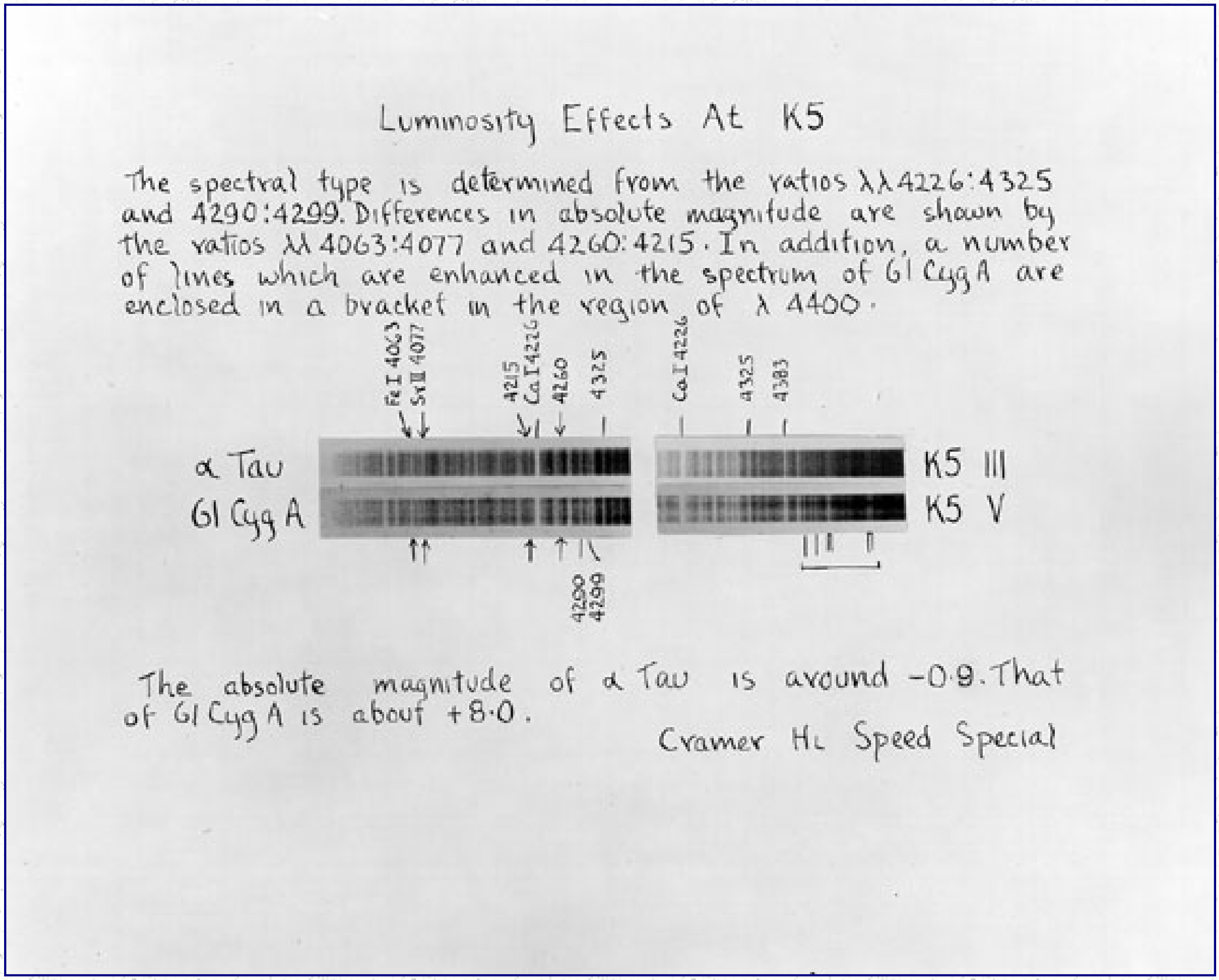
Luminosity differences are shown by the ratios λλ 4045:4077, 4063:4077 and 4325:4340. The break at λ4215 is no longer a sensitive indicator of absolute magnitude among the high luminosity stars. The ratio of the intensity of the two blends to the violet of λ 4144 changes with luminosity.



The absolute magnitude of δ And is around +1. The luminosities of the other stars are very uncertain; there can be little doubt, however, that they are arranged in order of decreasing luminosity. The absolute magnitude of ε Peg is probably around −4 or −5.

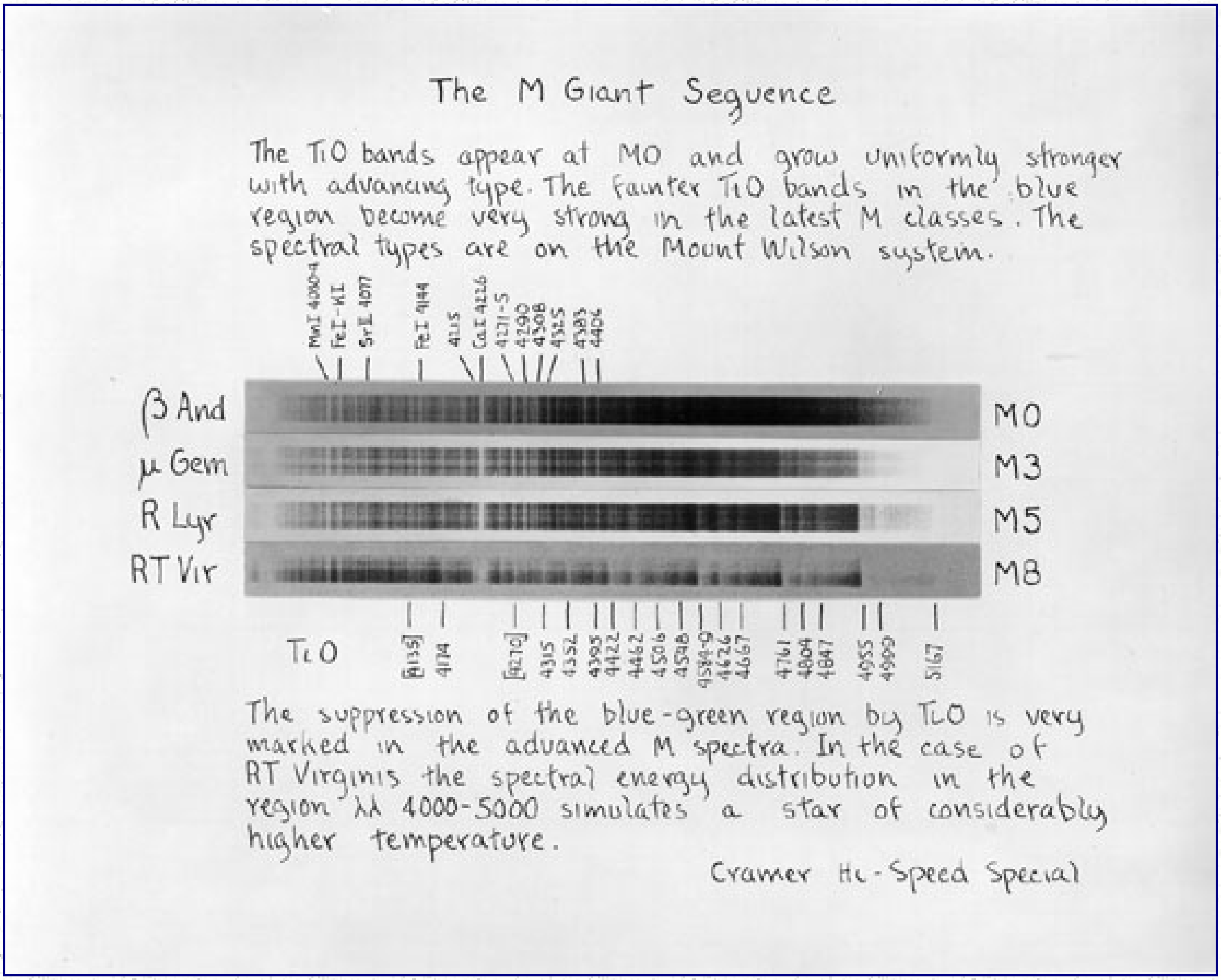
Cramer Hi-Speed Special

Plate 50


Luminosity Effects At K5
The spectral type is determined from the ratios λλ 4226:4325 and 4290:4299. Differences in absolute magnitude are shown by the ratios λλ 4063:4077 and 4260:4215. In addition, a number of lines which are enhanced in the spectrum of 61 Cyg A are enclosed in a bracket in the region of λ 4400.
FeI 4063
SrII 4077
4215
CaI 4226
4260
4325
CaI 4226
4325
4383
α Tau
61 Cyg A
K5 III
K5 V
4290
4299
The absolute magnitude of α Tau is around −0.9. That of 61 Cyg A is about +8.0.
Cramer HL Speed Special

Next Contents Previous

Plate 51

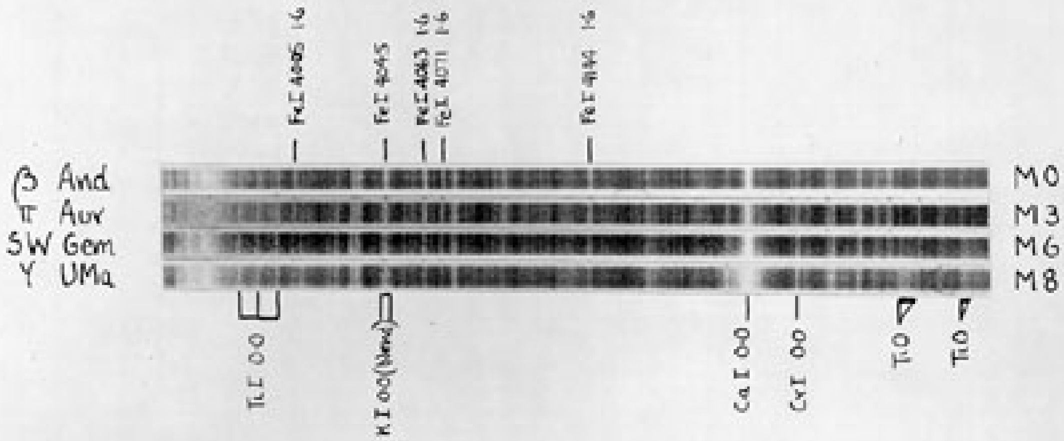


Next Contents Previous

Plate 52

The M Sequence Is A Temperature Sequence

The spectral types of the four stars were determined from the TiO bands in the blue-green region (not shown in the illustration). The arrangement in order of increasing band absorption has the following characteristics: the strong FeI lines having excitation potentials of around 1.6 volts grow systematically weaker; ultimate lines of TiI, CaI and CrI grow systematically stronger;

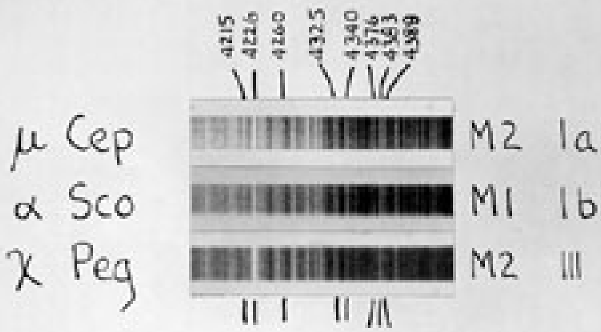


the KI pair situated on each side of FeI 4045, and blended with it on the spectra shown, become systematically stronger. This is shown by the change in the width of the line from M0 to M8. These changes indicate that stars having the strongest bands have also the lowest excitation temperatures among the M stars. They thus show that the TiO bands do not pass through a maximum of intensity. The plates were taken by Keenan with the McDonald 82-inch reflector and a spectrograph giving a dispersion of 65 A per mm at λ 4200. The progressive change in the line spectra of M giants was first described in detail by Merrill and his associates at Mount Wilson. Agfa Super Plenachrome Press

Plate 53

Luminosity Effects In The Early M Giants

The spectral types were determined from the intensity of the green TiO bands, which are not shown in the illustration. The line Ca I 4226 has a pronounced negative absolute magnitude effect. The CN break at λ4215 is present in μ Cep, possibly faintly present in α Sco, and probably absent in χ Peg.



Luminosity line ratios are: λλ 4215:4260, 4376:4383, and 4389:4383. The absolute magnitude of μ Cep is probably around −6, that of α Sco is near −4.0. χ Peg appears to be an ordinary M giant with an absolute magnitude of about 0.

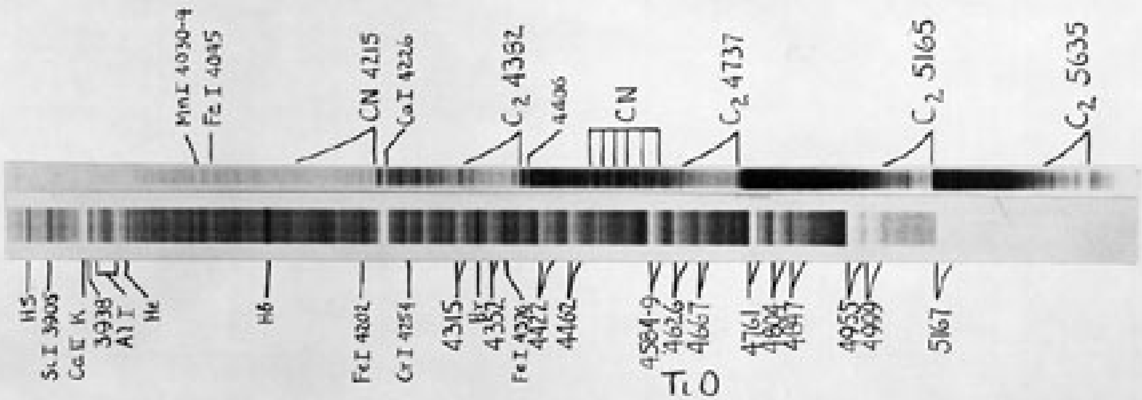
Cramer Hi-Speed Special

Next Contents Previous

Plate 54

A Carbon Star And A Long Period Variable

The spectrum of HD 52432 (upper) contains strong bands of C_2 and CN. Its spectral type on the R-N system is R5; this corresponds to an equivalent spectral type of around K4. The spectrogram was taken on Agfa Super Plenachrome Press Film.



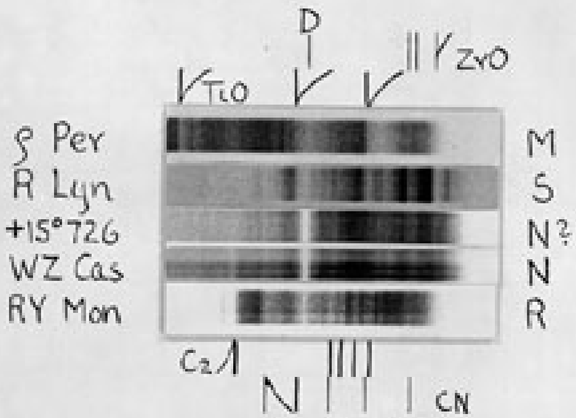
The spectrum of o Ceti (lower) has strong bands of TiO, and the ultimate lines of CaI, CrI and Al I are very strong in absorption. There are also a number of strong emission lines present, including the Balmer lines, Si I 3905, and Fe I 4202 and 4376. The spectrum was taken on Nov 8, 1940, when Mira was near the eighth magnitude, approaching light minimum. Cramer Hi-Speed Special

Contents Previous

Plate 55

The Banded Stars In The Visual Region

The various kinds of banded spectra can be recognized and separated from each other on plates of the yellow-red region having very low dispersion. The spectrum of +15°726 was recognized as having special interest at the Dearborn Observatory. It and the spectrum of WZ Cas give



evidence of very low temperature. The plates on which the three central spectra were obtained had sensitivity extending farther into the red than did those for ρ Per and RY Mon. Hα shows as a strong emission line near the right end of the spectrum of R Lyn. The spectra extend from around λ5400 to λ6600 (in the case of the N and S stars).