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The Spectral Classification of the F Stars of Intermediate Luminosity

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A general procedure in visual spectral classification is outlined which makes use of all significant spectral features in the available wavelength region. A grid of standard F-type stars of luminosity classes II–IV is given. This grid is on the MK system, but it defines a localized structure of higher internal precision than the latter. The revised (Morgan, Keenan, Abt) system is used for the determination of new types for 14 stars of the δ Scuti class. All are found to have luminosity classes above the main sequence, and a range in spectral peculiarities is found within the group.

THE MKK classification system (Morgan, Keenan, and Kellman 1943) and its revision (Johnson and Morgan 1953), the MK system, provide a two-dimensional grid which is defined by certain standard stars. Despite the rapidly increasing use of quantitative methods for stellar classification, the MK system continues to be useful as a frame of reference, and its usefulness would be increased if it were possible to improve the precision with which it is defined.

The increasing degree of complexity revealed by current investigations on metal richness, the metallic-line stars, helium-rich—and helium-poor—young stars, and other special categories of stellar spectra, has resulted in a progressive blurring of the field defined by the earlier MK system. A better-defined field in terms of the appearance of the spectral features is needed—before the complexity of the spectrum is reduced by *a priori* operations (abundance analyses; etc.).

The present paper is an attempt to sharpen the definition of the MK system for the F stars of intermediate luminosity class. Grating slit spectrograms having d scale of around 125 Å/mm, obtained with the 36-inch reflector No. 1 of the Kitt Peak National Observatory, were used for the purpose. The spectra were trailed to a width of 1.2 mm; this width is crucial for the classification described in the following.

I. CHARACTERISTICS OF THE FIELD FOR THE F STARS

We first describe the two-dimensional field for the F stars in terms of five criteria, (1) the low-level lines of Fe I and Mn I between λ3850 and Hγ, (2) the Balmer lines Hγ → H 11, (3) the H and K lines of Ca II, (4) the appearance of the G band, and (5) the strong lines of Fe II, Ti II, and other singly ionized metals. By use of these five categories we are able to construct a fairly smooth two-dimensional grid—with a few rather spectacular exceptions, such as the metallic-line stars and the weak metallic-line Population II objects. If we add the criterion of the relative strength of Sr II 4077, we can segregate members of the A-type peculiar strontium star group near class F0, and gain a useful additional luminosity discriminant for classes later than F2. We postpone for later consideration the metallic-line and weak-line star groups—and the Cepheids.

The five criteria listed above have the following general characteristics for the F0–G0 stars of luminosity classes II–IV: criterion (1) is an almost pure indicator of spectral type, criterion (2) is somewhat more sensitive to changes in spectral type than to luminosity class, criterion (3) is also more sensitive to temperature than to luminosity, but there are many F stars with abnormally weakened Ca II H and K, and criteria (4) and (5) are most useful for the determination of luminosity class, after an approximate spectral type has been found.

The process of classification was carried out as follows. (a) A preliminary spectral type was found by comparing the unclassified spectrum with the fundamental standards (which are marked with an asterisk in Table I); low-level lines and blends of Fe I and Mn I were used. (b) An approximate luminosity class was determined by use of lines and blends of Fe II and Ti II, again with reference to the fundamental standards. (c) Any gross peculiarities in the intensities of Ca II or the Balmer lines were noted. (d) All of the individual spectrograms were then intercompared and adjusted to compatible positions with respect to each other; for this purpose, all of the criteria listed above were used. The classification process was carried out without knowledge of color indices—or any other measured characteristics of the stars—and no type was changed after the colors were known.

The result of these operations is a two-dimensional array defined by the stars in Table I, and depends principally on the intensities of the strong lines of Fe I, Mn I, Fe II, and Ti II (and of Sr II for types later than F2). The types of the stars in Table I are defined approximately in terms of the metallic-line intensities of the Hyades main-sequence stars, which served as a frame of reference for the standards.

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1972AJ.....77...35M

TABLE I. MKA standard F stars above main sequence.

Name	HR	MKA
* 19 Sco	6081	A5 II
* θ^2 Tau	1412	A7 III
* ι UMa	3569	A7 IV
	7876	A9 II
32 Gem	2489	A9 III
	2557	A9 III
* α Lep	1865	F0 Ib
	292	F0 II
* ζ Leo	4031	F0 III
130 Tau	1990	F0 III
* δ Aql	7377	F0 IV
	7823	F1 II
	7222	F2 III
* β Cas	21	F2 III–IV
	1554	F2 IV
	8765	F2 IV
7 Sgr	6724	F3 III
	8071	F3 IV
	2811	F3 IV
55 Eri (ft)	1505	F4 IIIp**
* α Per	1017	F5 Ib
	7495	F5 II
	856	F5 III
48 Gem	2706	F5 IV
	3603	F6 II–III
	6531	F6 III
	6577	F6 III
25 Mon	2927	F6 III
	831	F6 III–IV
* α Tri	544	F6 IV
	4843	F6 IV
	3794	F7 IV–V
* 31 Com	4883	G0 III
81 Psc	339	G0 III

* 1505—Ca II *H*, *K*, greatly weakened; Sr II 4077 strong.

II. THE NEW STANDARDS

Table I gives MKA types for 32 stars having luminosity classes between II and IV–V, together with two Ib supergiants. All of the nonstandards are from a list of F stars considered to be located above the main sequence by I. J. Danziger and Sandra M. Faber; we wish to thank Dr. Danziger and Dr. Faber for furnishing us with this list.

Special mention should be made of the star HR 1505, which was classified by a compromise of conflicting criteria; the spectral type depends essentially on the metallic lines and the *G* band; the luminosity class is a compromise between Sr II 4077 and the enhanced lines of Fe II and Ti II; the *H* and *K* lines are abnormally weak. This star has a close spectroscopic resemblance to some of the δ Scuti stars discussed below.

The 25 other stars in Table I with types between A9 and F6, and having intermediate luminosity classes, define with good precision this section of the spectral type–luminosity class diagram. The revised standards of luminosity classes Ib and V will be discussed at a later time.

III. THE SIGNIFICANCE OF THE STANDARD MKA TYPES

The 25 nonpeculiar stars in Table I having types between A9 and F6, and luminosity classes between II and IV–V, constitute an autonomous, self-consistent, two-dimensional structure. It requires no calibration to establish its validity, and it furnishes independent information which can be combined with that of photometric and astrophysical investigations. A detailed description of the MKA structure in terms of photometric and spectrophotometric data can make practicable its use as a general astrophysical frame of reference, after the system has been expanded to include strong- and weak-lined stars.

IV. AN APPLICATION TO THE δ SCUTI STARS

We conclude by making a preliminary application of the frame of reference to a group of δ Scuti stars. The observing list was taken from Table 4 of Danziger and Dickens (1967). Data for 14 objects listed in Table II (the star β Cas has been added from Table I) were taken from Breger's catalogue (1969) of members of this class. The spectrograms are similar in characteristics to those used in determining the MKA types in Table I.

The columns in Table II list: (1) the HR number; (2) the name of the star; (3) the spectral type as compiled by Breger from various sources; (4) the MKA type; (5) marked peculiarities in Ca II *H* and *K*, when present; and (6) values of Δm_1 as listed by Breger. The stars are arranged in order of advancing MKA type.

From the data in Table II, we note that all of the δ Scuti stars listed have MKA luminosity classes brighter than class V, and that the spectra of these δ Scuti stars do not form a homogeneous group (the Ca II lines show a great range in intensity among objects having similar spectral types and luminosity classes). Evidence for the latter was first given by Eggen (1956) in his discovery

TABLE II. Revised spectral types for δ Scuti stars.

HR	Name	Sp.	MKA	Ca II	Δm_1
5329		A7 IV	A8 IV		
1706	14 Aur	A9 V	A9 IV		+0.008
1351	Hyades VB30	F0 V	F0 IV		+0.002
3888	29 UMa	F2 IV	F0 IV		+0.003
7928	δ Del	Am?	F0 IVp	Weakened	+0.003
5005		F0	F1 IV		−0.002
21	β Cas	F2 IV	F2 III–IV		−0.018
2107	1 Mon	F2 II	F2 IV		−0.009
1287	44 Tau	dF3	F2 IV–V		−0.012
5017	20 CVn	F0 II–IIIp	F3 III		−0.064
7020	δ Sct	F3 III–IV	F3 IIIp	Weakened	−0.037
3265		A5	F3 IIIp	v. weakened	−0.060
4715	4 CVn	F0	F3 IV		−0.028
3185	ρ Pup	F6 III	F5 IIp	Weakened	

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1972AJ.....77...35M

paper for the δ Scuti group. The weakening of the Ca II lines in two of these stars (20 CVn and HR 3265) is shown in Plate VII, p. 111; HR 6724, which has the same MKA type and luminosity class, is shown for comparison. Only the most extreme examples of Ca II weakening are classified as "peculiar" in Table II; the exact boundary between the "normal" and "peculiar" domains is a problem for future investigation.

The tabulated values of Δm_1 for the δ Scuti stars in Table II show a rather smooth, increasingly negative, run with MKA type. The sensitivity of the Δm_1 index to metal content in the F1–F4 stars has been found to be less than for F stars of later type (Strömgren 1963). For this reason, in addition to other uncertainties, the interpretation in terms of a progressively higher metal content with advancing MKA spectral type, for the δ Scuti stars of Table II, seems doubtful.

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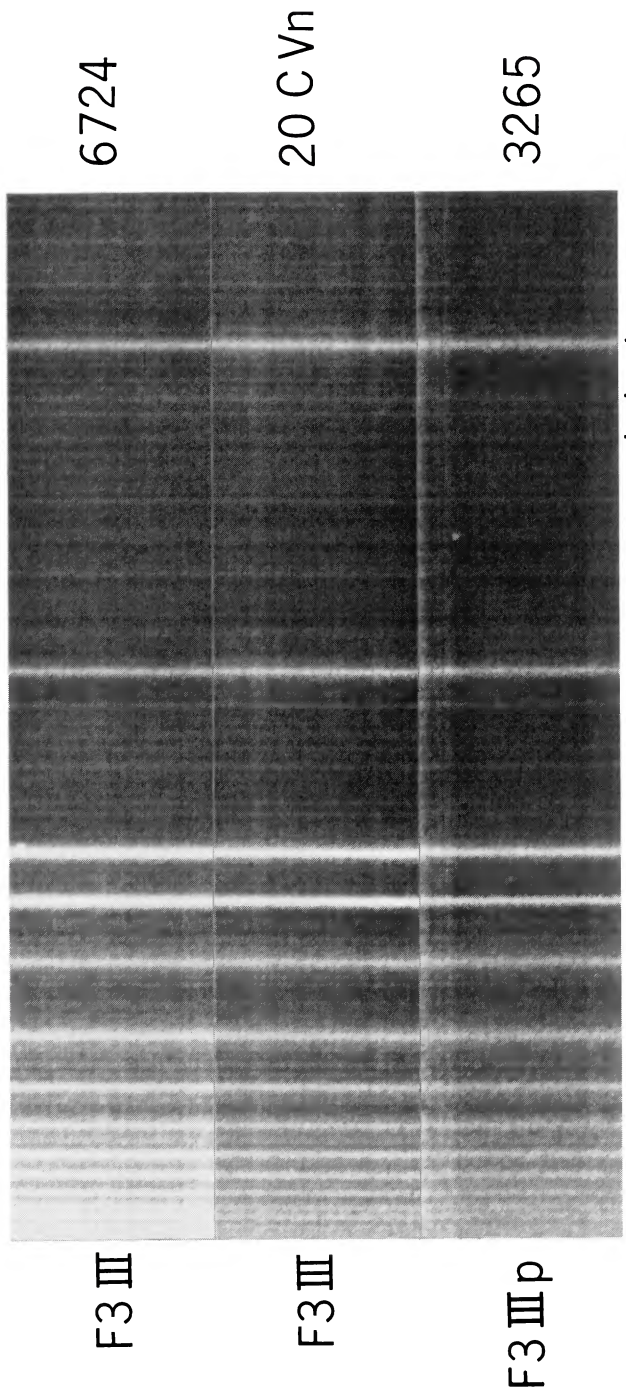


PLATE VII (Morgan and Abt, p. 35). Spectrograms of the normal F3 III star HR 6724 (top); the δ Scuti star 20 CVn (center); and the δ Scuti star HR 3265 (bottom). The spectral range is from near Hγ to near H 13. The *H* and *K* lines of Ca II are strongest at top, weaker at center, and weakest at bottom. The temperature-sensitive criteria marked include strong, low-level lines of Fe I and Mn I. Some luminosity-sensitive blends of Fe II and Ti II are also identified. The line Sr II 4077 is coupled with Fe I 4045; this ratio is highly sensitive to luminosity.

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