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SPECTRAL CLASSIFICATION OF SELECT DELTA SCUTI STARS. III.

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RESUMEN

Se presenta la clasificación espectral de un selecto grupo de estrellas Delta Scuti. Algunas de las estrellas consideradas han sido recientemente descubiertas y en aproximadamente la mitad de las estrellas consideradas no se tenía ninguna clasificación espectral anterior.

La magnitud absoluta y el color $(b-y)$ fueron derivados a partir del nuevo tipo espectral determinado; estos valores fijan su posición tanto en el diagrama H-R como en la relación Período-Luminosidad-Color.

ABSTRACT

A spectral classification of selected Delta Scuti stars has been carried out. Some of the classified stars have been recently discovered and in about half of the considered stars no previous spectral classification was reported.

The absolute magnitude and $(b-y)$ color were derived from the spectral type found for each star and these values fixed their location in both the H-R diagram and the Period-Luminosity-Color Relation.

Key words: **VARIABLE STARS – δ SCUTI STARS – SPECTROSCOPY**

I. INTRODUCTION

In previous papers (Peña, Peniche, and Warman 1980; Peniche, Peña, and Hobart 1981; hereinafter Papers I and II, respectively) some spectrograms of select Delta Scuti stars were classified. The results showed that, although most of the stars were bright, very few had their spectra determined unambiguously; that in some cases several classifications for the same star do not agree; that in most cases the spectra for the stars were taken from the catalogues and that only in very few cases new spectrograms were taken with the only purpose of spectral classification. These facts, together with the fact that an accurate spectral type fixes the position of star in both the H-R diagram and in the Period-Luminosity-Color relation (PLCR) (which in turn is useful in distance calibration or when modelling stellar interiors) encouraged the continuation of this work.

II. OBSERVATIONS

The spectrograms of the stars considered were taken at two different observatories. Most of the plates were obtained at the Observatorio Astronómico Nacional at San Pedro Mártir, Baja California, by one of us (R. Ortega). A 33-inch telescope with a Boller & Chivens spectrograph with a dispersion of 85 Å/mm was employed along with a Kodak IIaO emulsion. Spectroscopic standards from Johnson and Morgan (1953), and Morgan and Keenan (1973) were also taken with the same emulsion and at the same dispersion. These spectrograms were taken during two different observing seasons: from August 15 to 17 and from September 25 to 29, 1982.

At the Observatorio de Tonantzintla, Puebla, a 1-meter telescope with a Boller & Chivens spectrograph at a dispersion of 125 Å/mm with IIaO plates was utilized. The spectroscopic standards were the same as those of Papers I and II. The observations were carried out on July 12, 1980.

III. RESULTS

The spectral classification was done considering the classification criteria stated by Morgan and Keenan (1973) and the spectrograms of the Atlas of Stellar Spectra (Abt *et al.* 1968).

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The results are summarized in Table 1 that lists the several spectral classifications previously reported for each star. The first and second columns list the HR and the HD numbers; the third through the seventh columns, the previous spectral classifications from the Bright Star Catalogue (Hoffleit 1964), Cowley *et al.* (1969), Baglin *et al.* (1973) (MKA if it exists, otherwise MK), Breger's latest review (1979) and the Smithsonian Astrophysical Observatory Star Catalogue (1969), hereinafter SAO. The eighth column lists the classifications presented in this paper.

From the stars considered, the following was found:

a) *HR 114 (F0 IV)*

Its spectra is by all means analogous to the spectroscopic standard ϵ Cep. It has been previously reported (Crawford 1966) as an Am; and Nishimura (1969) assumes this spectral type also, but Smith (1971) considered it as a non-Am star and utilized it as a standard in a study about Am stars. Its spectrum (Figure 1 Plate) shows that the K line is not similar to that of an A but that of an F0. The metallic lines are in all respects similar to that of ϵ Cep and no line seems to be stronger than an F1. In this connection it is interesting to recall that a weak K line is one of the fundamental characteristics of the metallic line A type stars.

b) *HD 21479 (A7 III)*

Very little has been reported about this star. The only reference we came upon in the SAO that reports it as an A0. The relative intensity of the CaII K line with respect to the Hδ line indicates that this is an A7 star. The intensity of the λ4481 indicates that its luminosity class belongs to the giants. Its spectrum resembles that of the spectroscopic standard γ Boo.

c) *HD 24550 (F1 IV)*

This star has been previously reported as an A8n by Baglin *et al.* (1973) and Breger (1979), the SAO reports it as an F0. In fact, the ratio of λ4030-34:λ 4128-32 establish it to be of a slightly later type, perhaps an F1. Its luminosity class, determined from the relative intensity of λ4172: λ4132 and λ4172: λ4226 locates it above the main sequence, with a luminosity class IV.

d) *HR 1412 (A7 III)*

As in the case of γ Boo this Delta Scuti Star, θ^2 Tau, is a spectroscopic standard; according to Johnson and Morgan (1953) it is a A7 III. The spectrum of this star agrees with this classification and was utilized as a standard for the classification of the other stars.

e) *HR 1611 (F0 V)*

This star has been previously reported as an F0 (Hoffleit 1964, SAO). The spectrum obtained agrees with this criteria; the relative intensities of the Mn I 4030-34: λ4128-32 and the appearance of λ4300 indicate it to be an F0. While the ratio of λ4172: λ4226 indicate that it is a main sequence star.

TABLE 1

SPECTRAL TYPES OF SELECT DELTA SCUTI STARS

Name		Previous Reported Classification					
HR	HD	Hoffleit	Cowley *et al.*	Baglin *et al.*	Breger	SAO	This paper
114	2628	Am	...	Am	F0 IV	F0	F0 IV
...	21479	...	...	...	...	A0	A7 III
...	24550	...	...	A8n	A8n	F0	F1 IV
1412	28319	A7 III	...	F0 IV	A7 III	F0	A7 III
1611	32045	F0	...	F0 IV	...	F0	F0 V
...	37819	...	...	...	...	F8	F5p
4828	110411	A0	A0 V	...	...	A0	B9 V
...	159223	...	...	...	...	A5	A7 V
7331	181333	F0	...	F0	F0 III	F0	F5 III
8024	199603	A3	F0 IV	...	...	A3	A9 IV
...	200356	...	...	...	...	F2	F5 III
8102	201707	A5	δ Del	...	δ Del	A5	F0 V
8494	211336	F0 IV	...	F0 IV	F0 IV	F0	F0 IV
8686	215874	F0	...	...	F1 IV	F0	F1 IV
8880	220061	A5	A5 V	A5 V	A5 V	A5	A5 V
9039	223781	A3	...	...	A3	A3	A5 III

f) *HD 37819 ($F5_p$)*

This faint Delta Scuti star seems to be one of the latest pulsators in spectral type. Hydrogen λ3889 appears faint and diffuse with respect to Calcium II H and K. Also, Fe I 4045 and Ca I 4226 are very much weaker than Hγ and Hδ as should appear in an F5 spectral type. Some special features make the spectrum of this star peculiar: λ4077 appears unusually strong; the blend λ4128-32 is intense. The lines at λ4215, λ4172 are easily discernible. It was classified before as an F8 due to the intensity of the metallic lines but later it was classified as an F4 IIIp. However, since the luminosity class is determined utilizing the λ4077 and λ4172 lines, which are anomalous in this spectrum we prefer not to assign a luminosity class to this star.

g) *HR 4828 (B9 V)*

When compared to the spectroscopic standard of the A0 V type the Ca II H line is slightly weaker and thus, it belongs to an earlier type, B9. No helium lines are discernible, and the hydrogen lines are broad; therefore, it is a main sequence star. This star would be one of the earliest among the Delta Scuti stars or as Bartolini *et al.* (1980) established, it could be a "Maia Variable" linking the Delta Scuti stars with the Beta Canis Majoris stars.

h) HD 159223 (A7 V)

The Henry Draper Catalog and the SAO Catalog report this as an A5 star. When compared to the spectroscopic standard of o Cas both spectra look alike. The intensity of Hδ and Ca II K lines indicate an A7. The G band starts to be discernible, this fact and the lack of metallic lines support this statement. The luminosity was estimated by the ratio λ4417: λ4481.

i) *HR 7331 (F5 III)*

This star was classified in a previous paper (Peniche, Peña, and Hobart 1981) as an F0 III. A recent spectrogram taken for this work clearly indicates that at present the spectrum is of a later type. The weakness of the Hγ and Hδ with respect to Ca II H and K lines establish it as an F5. The ratio of FeI λ4063: λ4077 and λ4271: λ4172 fix its luminosity class as a giant, therefore, it can be concluded that the spectrum is variable although Breger (1982) found that the F5 III classification is in agreement with the type-based on a spectrum of his own. It can be seen from Figure 1 that the features in both spectra are different.

j) *HR 8024 (A9 IV)*

This Delta Scuti star was previously listed as an A3 by Hoffleit (1964) and in the SAO. Its spectrum shows that the lines of Ca II K and Hδ are similar in intensity; this fact establishes it as an A9. The luminosity indicator of λ4417: λ4481, and the intensity of λ4226 and the blend λλ4030-34 suggest that this should be of class IV.

k) *HD 200356 (F5 III)*

The spectrum of this recently discovered Delta Scuti star (González and Peña 1982) shows a high metallic content. Fe I 4045 and Ca I 4226 appear clearly discernible, but weaker than Hγ and Hδ. The G band is conspicuous, as it should be an F5 type; λ4172 is stronger than λ4272, and therefore the luminosity class is III. This star is a Delta Scuti pulsator of a very late spectral type.

l) *HR 8101 (F0 V)*

Both Hoffleit (1964), and SAO report it as an A5. Later, Cowley *et al.* (1969), suggest that it could be a δ Del and is listed in Breger review paper (1979) with this spectral type.

According to Houck, Irvine, and Rosenbush (1974), this type of stars is characterized by the typical, unusually narrow Ca II H and K lines and the same anomalous metal abundance present in the Am stars. The spectrum of HR 8102 does not show these features. Its Ca II H and K lines are normal for an F0 star and the λ4481 with respect to λ4417 indicate it to be on the main sequence.

m) *HR 8494 (F0 IV)*

This star was established by Johnson and Morgan (1953) as a standard in its class. Breger discovered its variability in 1966, which was later confirmed by López de Coca, Costa, and Rolland (1979). In this work we have checked its spectral type and later considered it as a standard for classification purposes.

n) *HR 8676 (F1 IV)*

Although it was first reported as a F0 (Hoffleit, SAO) later, in Breger's compilation, it was listed as an F1 IV. Comparing its spectrum with that of ε Cep, a spectroscopic standard, an agreement with the F1 IV was obtained. This is a small discrepancy with the classification reported by Hoffleit (1964) that should not affect any previously derived results.

o) *HR 8880 (A5 V)*

This star has been reported before as an A5 V by Breger and by some other authors. When compared to the spectroscopic standard δ Cas, the relative intensities of the Ca II K and Hδ lines indicate it to be an A5 star and the relative intensities of λ4417 to λ4481 imply that it belongs to the main sequence.

p) *HR 9039 (A5 III)*

The ratio of Ca II K/Hδ indicates that this star is an A5. The luminosity class is derived by the ratio λ4417/λ4481; according to this criterion HR 9039 is a giant star of luminosity class III. Its spectral type, when compared to the standard stars is quite similar to that of α Oph.

IV. DISCUSSION

About half of the stars considered in this paper do not have previous spectral classifications and in most cases the spectral type assigned was only from Hoffleit (1964). Only few have been observed for classification purposes, mainly by Cowley *et al.* (1969) (as we can see in Table 1). An accurate spectral classification allows a determination of the absolute magnitude M_v and the $(b-y)$ color and consequently the location of these objects on the H-R diagram and on the Period-Luminosity-Color Relation (PLCR) can be determined.

In order to place them accurately the M_v value was derived from the M_v versus Spectral Type as in Mihalas and Routly (1968) which, when combined with the $(b-y)$ versus Spectral Type relation (Crawford 1975, 1979) fixes the position of each star on the H-Rdiagram (Figure 2). All but HR 4828 and HD 223781 lie within the instability limits. It should be kept in mind that HR 4828 shows an early spectral type for this kind of variables and that Bartolini *et al.* (1980) suggest it might be a link between the Beta Cepheid stars and the Delta Scuti stars.

With respect to the PLCR not much can be said since the periods of very few stars have been accurately determined and in some cases no period has been reported; for those stars with an assigned period, and with the $(b-y)$ and M_v previously derived, the relation $M_v - 8.46\,(b-y)$ as in Breger (1979) was considered. The location of these stars in the PLCR diagram is presented in Figure 3. The only star that is far from the linear relation is HR 1611 which has one of the longest periods among the Delta Scuti stars known.

In paper II some evidences that prove the constancy of the spectral types in Delta Scuti stars were given. One exception to this rule seems to be HR 7331 which was previously classified as an F0 III and whose recent spectrum shows that it belongs to the F5 III class. It is a well-known fact that those stars that have large amplitude of variation show appreciable changes in their spectral types but HR 7331 has an amplitude variation of only 0.6 mag. so, as γ UMI (Paper II) should not show such a large change in its spectrum. We plan, and encourage the monitoring of this star, to observe its spectroscopic and photometric behavior.

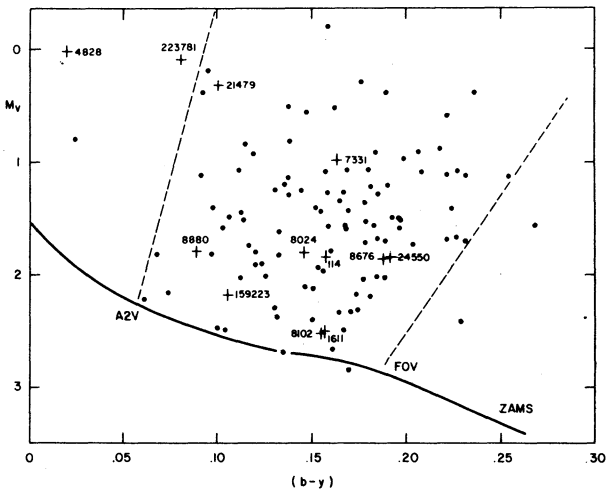

Fig. 2. Position of the δ Scuti stars in the H-R diagram. Filled circles are taken from Breger (1979). Crosses indicate the position of the considered stars. Dashed lines refer to the instability strip borders.

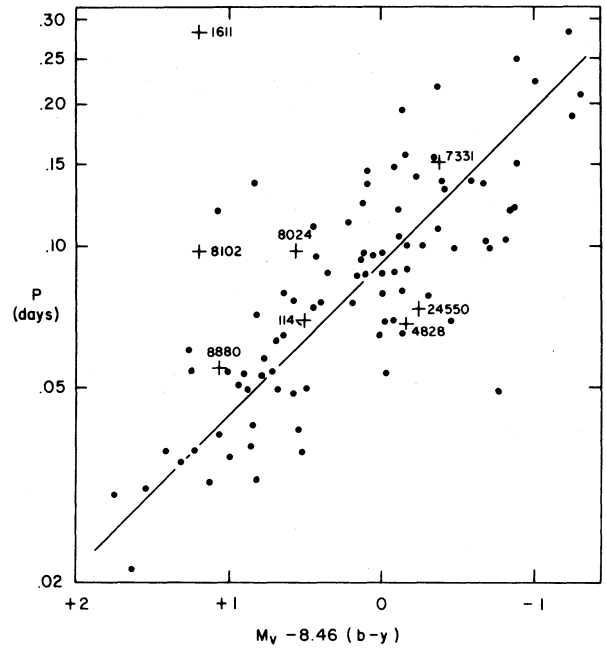

Fig. 3. Period-Luminosity-Color Relation as in Breger 1979. Filled circles are taken from this reference. Crosses indicate the new positions of the stars considered in this study; $(b-y)$ values are taken from Crawford (1975 and 1979).

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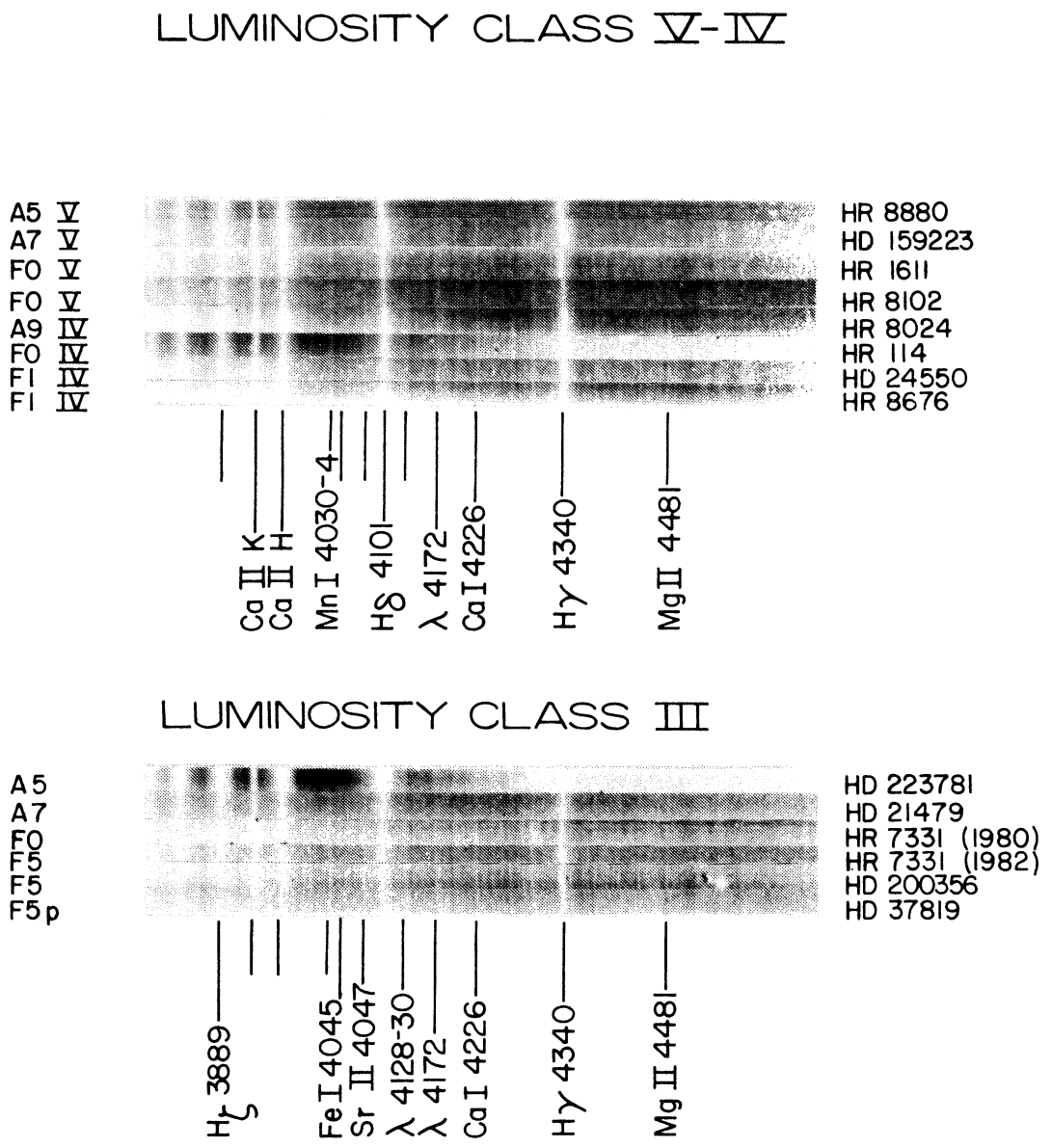

Fig. 1. Spectrograms of the Delta Scuti stars considered. The spectral range is from near Hγ to near H10 and is centered at Hδ. Dispersion is 85 A mm^{-1}.