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METALLICISM AND PULSATION: AN ANALYSIS OF THE DELTA DELPHINI STARS

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ABSTRACT

Fine abundance analyses of eight δ Delphini stars and one δ Scuti star relative to four comparison standard stars are presented. Five of the δ Delphini stars are shown to have abundances most similar to the evolved Am stars. It is argued that these abundances are different from the main-sequence Am star and Ap star abundances, and that similarities to the Ba II star abundances are coincidental. We suggest that the anomalous-abundance δ Delphini stars are evolved metallic-line stars on the basis of their abundances, position in the (β, M_v) plane, inferred rotation velocities, and perhaps their binary incidence. Some of the δ Delphini stars are δ Scuti pulsators. We argue that pulsation and metallicism are mutually exclusive among the classical Am stars but may coexist in other stars related to the classical Am stars. A preference for the diffusion-hypothesis model for the metallic-line stars is stated and supported, and the implications of the coexistence of pulsation and diffusion are discussed.

Subject headings: stars: abundances — stars: δ Scuti — stars: metallic-line — stars: pulsation

I. INTRODUCTION

The δ Delphini stars were defined as a class by Bidelman (1965), who designated 15 of 82 metallic-line stars as δ Delphini from an objective-prism survey. The only clarification of the classification was that the δ Delphini stars are metallic-line stars "in which the difference between the metallic-line type and the K-line type is rather small." The class was used by Cowley and Cowley (1964), who classified a star as having a spectrum "like δ Del." They (Cowley and Cowley 1965) reexamined Bidelman's Am and δ Delphini stars using slit spectra, and changed the classification of some stars but did not elaborate on the δ Delphini classification.

Cowley (1968) states that "the metallic line spectrum [of a δ Delphini star] resembles that of an F2 IV star but the hydrogen and ionized calcium lines are very narrow." This description is expanded in the Bright A Star Catalog (Cowley *et al.* 1969) in the description of δ Del itself: "The spectrum of δ Del shows rather narrow but equal H and K lines. Hydrogen lines are narrow; metallic line spectrum is rich and similar to that of a late A metallic line star." It is further explained (Cowley and Crawford 1971) that λλ 4173–4178 (Fe I, Y II, Fe II) and λ 4150 (Zr II) are especially enhanced, whereas λ 4417 (Ti II) is weak, as are the other metals (Cowley 1973).

In the defining paper for the MKA system for F giants, Morgan and Abt (1972) classify 14 of the 16 δ Scuti variables listed by Danziger and Dickens (1967). Four of these stars, including δ Del itself (F0 IVp), are noted to have peculiar spectra in which the Ca II H and K lines are weak for the MKA type. It is also noted that all of the δ Scuti variables that they classify have a luminosity class brighter than class V. Malaroda (1973, 1975) uses the MKA criteria for δ Scuti variables with peculiar spectra to classify some stars as δ Delphini. We agree that the MKA peculiar δ Scuti stars are, for classification purposes, δ Delphini stars, but we believe that there is a possible confusion between the δ Delphini and δ Scuti classes which should be clarified.

We use the δ Scuti classification to refer to photometrically variable stars within 3 magnitudes of the main sequence, with periods between 0.5 and 5 hours, and with amplitudes generally less than a few hundredths of a magnitude (Baglin *et al.* 1973). They are interpreted as pulsational variables lying in the extension of the Cepheid instability strip where it crosses the main sequence between spectral types A2 and F0. We use the δ Delphini classification to refer to stars with spectra similar to that of δ Del itself—that is, late A and early F subgiants and giants with disparate K-line and metal-line spectral types. Delta Scuti is a photometric classification and δ Delphini a spectroscopic classification; the two, as will be shown, cannot be used interchangeably.

Following the initial calculations of Michaud (1970), Watson (1970, 1971) and Smith (1971) suggested that element diffusion could account for the anomalous abundance patterns seen in the metallic line stars. Smith (1971, 1973*a*) used his extensive observational data to build a qualitative model for the Am stars in which it was suggested that element diffusion occurs in the radiative zone between the H I, He I, and the He II ionization zones. This model explains the observed abundance anomalies, their temperature dependence, the low-temperature cutoff of the Am domain,

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and the correlation between metallicism and rotation. The major drawback of the model is that the diffusion velocities are predicted to be on the order of 10^{-5} cm s^{-1}, whereas there is little theoretical evidence indicating whether stability against turbulent or convective mixing on that velocity scale is plausible or not. Latour *et al.* (1975) suggest that convective overshoot from the He II ionization zone may disrupt the above radiative zone sufficiently that element diffusion may not be able to occur there.

Breger (1970) showed that, in general, Am stars do not pulsate, and he hypothesized (Breger 1972) that, within the diffusion model for A stars, either (i) pulsation disrupts the extreme stability necessary for diffusion to occur to produce an Am star, or (ii) in a star in which diffusion does occur the helium sinks out of the He II ionization zone, thus damping the driving mechanism for pulsation in δ Scuti stars. Baglin (1972) and Vauclair *et al.* (1974) calculate that, in a star in which diffusion occurs, helium sinks rapidly from the He II ionization zone. Several stars have been labeled pulsating Am stars, but Kurtz *et al.* (1976) have shown that other explanations are more plausible in each of these cases. There is at present no known exception to the exclusion between the classical Am stars and the δ Scuti pulsators.

Some of the δ Delphini stars, however, appear to be related to both the Am stars and the δ Scuti stars. As these δ Delphini stars are subgiants and giants with Am-like spectra, one might *a priori* postulate that they may have evolved from Am stars. Some of the δ Delphini stars are also large-amplitude δ Scuti pulsators. This leads us to ask, Is there a region of the H-R diagram where pulsation and metallicism can coexist? If so, what effect does this have on the plausibility of the diffusion hypothesis as applied to the Am stars and to the δ Scuti variables? What is the physical nature of the δ Delphini stars? In this paper we will begin to answer these questions.

In § II we analyze *uvbyβ* photometry of the δ Delphini stars and compare it with *uvbyβ* photometry of the metallic-line stars. In § III the relationships among rotation, pulsation, and metallicism and their implications for the δ Delphini stars are discussed. Sections IV, V, and VI present the abundance analyses of eight δ Delphini stars and one δ Scuti star relative to four comparison standards. Section VII mentions what is known about the binary incidence among the δ Delphini stars, and § VIII is a discussion of the nature of the δ Delphini stars and their significance to our understanding of the metallic-line phenomenon and pulsation in the δ Scuti stars. In § IX we speculate on the nature of the proposed coexistence of diffusion and pulsation. In Appendix A we define the various subclassifications of the metallic-line and related stars as they are used in this paper.

II. PHOTOMETRY

The δ Delphini stars are a spectroscopically defined class of stars. Photometry, therefore, provides independent information about these stars which may be used to help determine whether the members of the class are astrophysically related. In discussing these stars we find it convenient to break them up into two subgroups based on their apparent visual magnitudes and the source of their spectral-type classifications. The first group we will refer to as the bright δ Delphini stars. They are stars classified δ Delphini or Fp from slit spectra by Cowley *et al.* (1969), Cowley and Crawford (1971), Morgan and Abt (1972), and Malaroda (1975) and which have $m_v < 6.7$ mag. The second group we will refer to as the faint δ Delphini stars. They are stars originally classified as δ Delphini by Bidelman (1965) from objective-prism plates and later reclassified by Cowley and Cowley (1965) using slit spectra. They have $m_v > 6.4$ mag. There is some overlap in apparent visual magnitude between the two subgroups, so we reiterate that the subdivision is for convenience of discussion only, with no *a priori* implication about the physical nature of the members of each group.

Table 1 lists the photometric indices of the *uvbyβ* system from Lindemann and Hauck (1973) for the bright δ Delphini stars. Table 2 lists the indices obtained by the author for the faint δ Delphini stars along with the classification of those stars by Bidelman (1965) and by Cowley and Cowley (1965).

a) *uvbyβ Photometry of the Faint Delta Delphini stars*

Observations were obtained on 1974 September 6 and September 8 and on 1975 February 15 with the University of Texas Volksphotometer attached to the McDonald Observatory 76 cm telescope. Each

TABLE 1

BRIGHT DELTA DELPHINI STARS

HR	V	$b - y$	m_1	c_1	β	Reference*
421....	5.68	0.208	0.151	0.674	2.726	4, 6
1706....	5.06	0.130	0.180	0.998	2.799	1
1974....	6.44	0.160	0.175	0.764	2.746	1
2094....	5.28	0.178	0.186	0.744	2.768	2
2100....	5.88	0.116	0.218	0.952	2.789	1
2255....	6.67	0.224	0.193	0.937	2.753	3
2557....	5.98	0.221	0.142	1.023	2.741	3
3185....	2.88	0.259	0.215	0.731	2.715	2, 5
3228....	6.38	0.174	0.221	0.831	2.775	3
3265....	6.30	0.196	0.230	0.786	2.753	5
3649....	6.34	0.204	0.171	0.630	2.733	4
4760....	5.37	0.118	0.211	0.996	2.830	1
5017....	4.71	0.180	0.231	0.913	2.780	5
6492....	4.30	0.257	0.176	0.685	2.706	2
6561....	3.54	0.152	0.203	0.890	2.790	2
7020....	4.72	0.214	0.197	0.830	2.749	2, 5, 6
7859....	5.03	0.254	0.263	0.656	2.724	2
7928....	4.53	0.191	0.162	0.853	2.739	1, 5
7984....	5.08	0.108	0.209	0.897	2.840	1
8102....	6.44	0.189	0.169	0.913	2.766	1
8322....	2.83	0.184	0.186	0.744	2.768	1
8787....	4.27	0.253	0.242	0.644	2.733	2

* Reference for the δ Delphini classification: (1) Cowley *et al.* 1969, (2) Malaroda 1973, 1975, (3) Cowley and Crawford 1971, (4) Cowley 1973, (5) Morgan and Abt 1972, (6) Cowley and Fraquelli 1974.

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TABLE 2

FAINT DELTA DELPHINI STARS

HD (1)	V (2)	$b - y$ (3)	m_1 (4)	c_1 (5)	β (6)	Spectral type* (7)	Spectral type* (8)
3448......	8.96	0.238	0.231	0.735	2.755	F3 V	δ Del
7119......	7.53	0.195	0.221	0.787	2.757	δ Del	...
18460......	8.40	0.219	0.210	0.778	2.799	F3 V	δ Del
25515......	8.64	0.254	0.175	0.758	2.697	F3 III	δ Del
30110......	7.43	0.192	0.202	0.729	2.760	δ Del	δ Del
39390......	8.46	0.199	0.183	0.701	2.723	δ Del	δ Del
47606......	7.29	0.130	0.208	1.000	2.813	δ Del	Am
69682......	6.47	0.184	0.195	0.712	2.761	F0 IV	δ Del
72792......	7.59	0.217	0.223	0.726	2.738	δ Del	δ Del
78388......	7.56	0.230	0.168	0.714	2.709	F0 III	δ Del
81772......	8.20	0.176	0.237	0.817	2.803	F0 IV	δ Del
172743......	7.63	0.217	0.192	0.821	2.771	F0 V	δ Del
179641......	7.81	0.205	0.205	0.730	2.755	F0 IV	δ Del
213143......	7.80	0.237	0.228	0.754	2.753	Fm	δ Del
213634......	8.07	0.154	0.233	0.751	2.850	F0 V	δ Del
223247......	8.18	0.190	0.200	0.791	2.755	F0 IV	δ Del

* Classification in col. (7) according to Cowley and Cowley 1965; classification in col. (8) according to Bidelman 1965.

observation consisted of four consecutive 10 s integrations in each filter in the sequence $\beta_n\beta_w ybvuuvby\beta_w\beta_n$, giving a total of 80 s integration time in each filter. Thirty *uvby* standards (Crawford and Barnes 1970) and 30 Hβ standards (Crawford *et al.* 1966) were observed in the same manner. Extinction coefficients were determined on 1974 September 6 and applied to both the 1974 September 6 and September 8 observations. Mean McDonald Observatory extinction coefficients were applied to the 1975 February 15 data. Transformation of the program stars to the standard system was done using linear relations for y, $b - y$, and β, while a color term was included in the m_1 and c_1 transformations as given by Crawford and Barnes (1970). The mean errors (in mag) per star determined from the standard stars for all three nights are $\sigma_y = \pm 0.02$, $\sigma_{b-y} = \pm 0.006$, $\sigma_{m_1} = \pm 0.008$, $\sigma_{c_1} = \pm 0.009$, and $\sigma_\beta = \pm 0.011$.

b) *A Comparison of the β and $b - y$ Temperature Indices*

Color excess, E_{b-y}, can be calculated for the δ Delphini stars by applying Crawford's (1975) calibration of intrinsic color, $(b - y)_0$, in terms of the Hβ index: $(b - y)_0 = 2.943 - \beta - 0.09\delta c_1 - 0.2\delta m_1$. In addition, absolute magnitudes can be calculated using Crawford's (1970) calibration of the zero-age main sequence (ZAMS) and $\Delta M_v = 8\delta c_1$. The rms error in M_v for one star is ± 0.3 mag, which corresponds to an error in distance modulus of about 15%. Figure 1 is a plot of E_{b-y} versus distance derived using the above calibrations, and we find that there is a preponderance of positive color excesses. The dashed line in Figure 1 represents the expected color excess-versus-distance relation if one applies a mean reddening law assuming that $E_{b-y} = 0.46$ mag kpc^{-1}.

For stars as close as these, a mean reddening law is not appropriate because of the patchiness of the interstellar medium. It is indicative, however, that some of the large color excesses, especially for the more distant objects, may be due in part to interstellar reddening. Some of these stars have large δm_1 indices, indicating metal line blocking in their spectrum, which may also account for their color excesses. Figure 2 is a plot of β versus $b - y$ (observed) for the δ Delphini stars and for a group of Am stars and a group of A and F giants selected from Cowley *et al.* (1969). The distributions of the three groups are similar, which further supports the thesis that reddening (as in the giants) or line blocking (as in the Am stars) can account for most of the color excesses in the δ Delphini stars.

Two stars, HR 1974 and HR 2100, have unusual negative color excesses. This could possibly be caused by weak Hβ indices as might be expected in a binary in which the hydrogen lines of the primary are partially filled in by the radiation of a cooler companion.

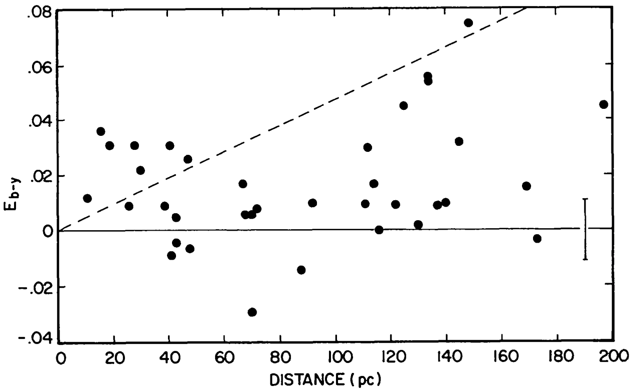

FIG. 1.—Color excess, E_{b-y}, versus distance for the δ Del stars, both computed from *uvbyβ* photometry assuming Crawford's (1970, 1975) calibrations apply. The dashed line represents the expected color excess versus distance relation assuming a mean reddening law with $E_{b-y} = 0.46$ mag kpc^{-1}.

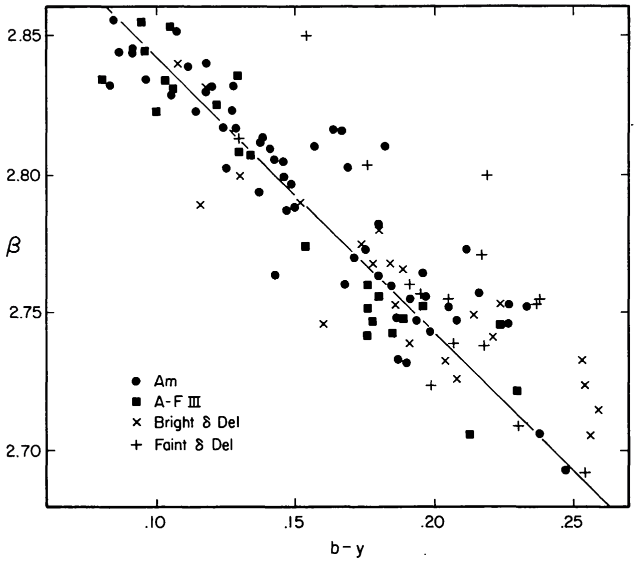

FIG. 2.—Comparison of the β and $b - y$ temperature indicators for the δ Del stars, and for a group of A–F III stars and a group of Am stars taken from Cowley *et al.* (1969). The solid line represents the calibrated (Crawford 1975) relation $b - y = 2.943 - \beta$ without the δm_1 or δc_1 terms.

HR 2100 is a known spectroscopic binary (Nadeau 1952), but nothing is known about the binary nature of HR 1974.

Since Hβ does not suffer from line blocking as severely as does $b - y$, nor from reddening, we have chosen to discuss the δ Delphini stars further in terms of the Hβ index, which should be a more meaningful temperature indicator for these stars than $b - y$.

c) *Metallicity Index*

The description of δ Del itself (Cowley *et al.* 1969)—"metallic line spectrum is rich and similar to that of a late A metallic line star"—makes one suspect that the metallicity index, m_1, might be enhanced in the δ Delphini stars as it is in many of the Am stars. Figure 3 is a plot of m_1 versus β for the δ Delphini stars and for a random sample of Am stars selected from the catalog of Lindemann and Hauck (1973). The mean relations for the field-star and Hyades main sequence have been drawn in with error bars encompassing 75% of the sample used to define the relation.

About two-thirds of the δ Delphini stars lie within the scatter of the field-star main-sequence relation, but the other one-third do appear to have the high m_1 index indicative of increased metal line blocking, with several of them lying in the Am domain in this plot. Two of the stars, HR 7859 and HR 8787, classified δ Delphini by Malaroda (1975), have very large m_1 indices and are near the cool border of the Am domain. They have been previously classified as g?F5 and F6 IV, respectively (Hoffleit 1964). As they are southern stars, we have not yet observed them, but we give them special notice here for their interesting position in the (β, m_1) plane and their spectral type.

Some caution must be used in inferring metallicity from the m_1 index. First, some of the metallic-line stars do not have abnormally high m_1 indices (Milton and Conti 1968). A few of these are plotted in Figure 3. Second, the main-sequence relations may not apply to giant stars (Hauck 1971; Baglin *et al.* 1973). For some giants, m_1 decreases relative to the main-sequence value at the same β, so that a giant with an increased metal abundance may have an m_1 index very near the main-sequence value at that β. The high m_1 indices of some of the δ Delphini stars very probably imply a high metallicity in those stars, but the normal m_1 indices of the rest do not necessarily imply a normal metallicity.

d) *Position in the* (β, M_v) *Plane*

Using Crawford's (1970) calibration of M_v for A stars, we have plotted in the (β, M_v) plane the faint

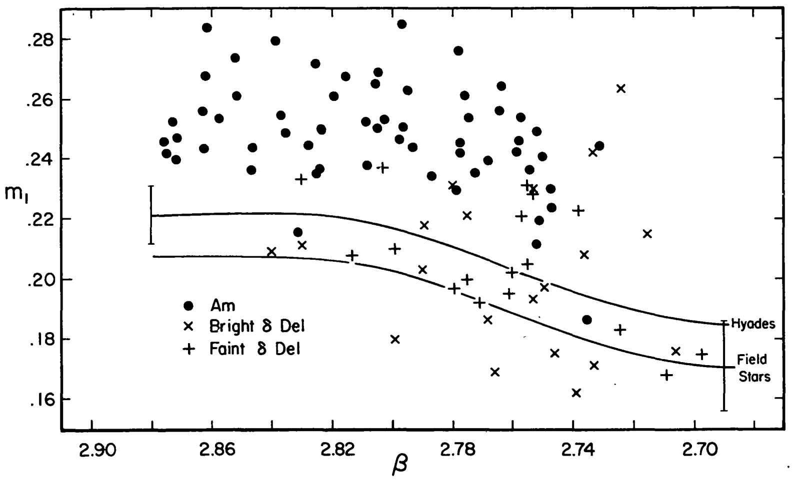

FIG. 3.—The metallicity index, m_1, in the δ Del stars compared with a sample of Am stars selected from the catalog of Lindemann and Hauck (1973). The solid lines represent the mean m_1, β relation for field stars (Crawford 1970) and for the Hyades (Breger 1968). The error bars are drawn to include 75% of the sample from which the mean relations were derived.

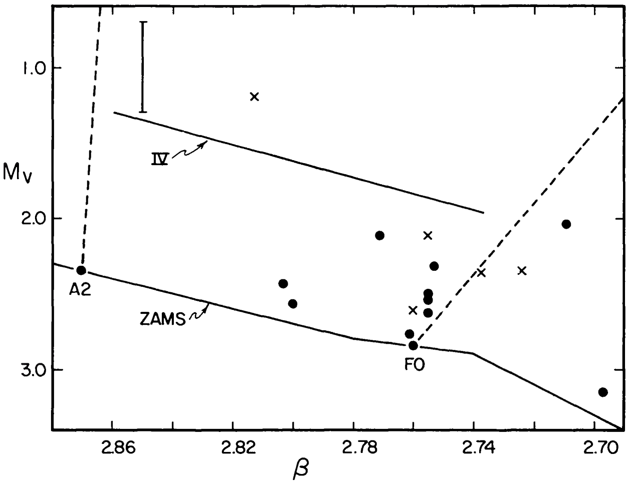

FIG. 4.—The faint δ Del stars. Crosses represent stars classified δ Del by both Bidelman (1965) and Cowley and Cowley (1965). The dashed lines delineate the observed instability strip (Baglin *et al.* 1973). The luminosity class IV mean relation is taken from Allen (1963).

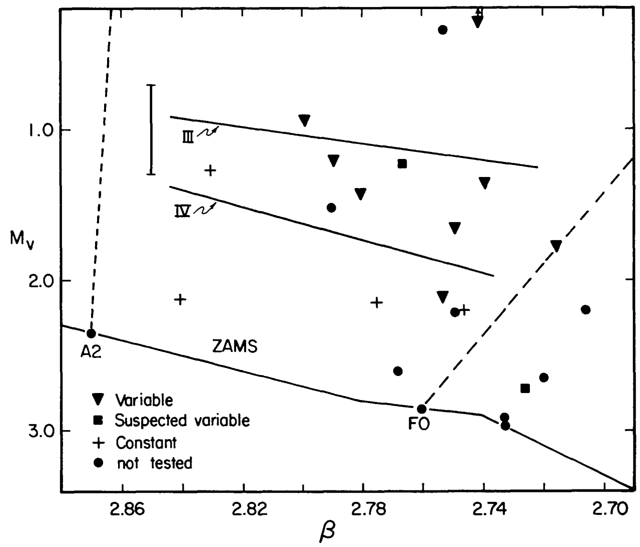

FIG. 5.—The bright δ Del stars, indicating the stars which have been tested for light variability. The dashed and solid lines are the same as in Fig. 4.

δ Delphini stars in Figure 4 and the bright δ Delphini stars in Figure 5. The ZAMS is as given by Crawford (1970), while the dashed lines represent the observed boundaries of the instability strip near the main sequence (Baglin *et al.* 1973). The error bars represent the internal uncertainty in the M_v calibration of ± 0.3 mag. The lines of luminosity class are taken from Allen (1963).

The faint δ Delphini stars in Figure 4 seem, with a few exceptions, to be a homogeneous group of late A and early F main-sequence and subgiant stars. The crosses represent the faint δ Delphini stars that were so classified by both Bidelman (1965) and Cowley and Cowley (1965). The bright δ Delphini stars in Figure 5 show much more scatter. Most appear to be A subgiant and giant stars, while several are F main-sequence stars and one, HR 2557, is a bright, luminosity-class III star.

e) Variability

Some of the δ Delphini stars show periodic light variability characteristic of pulsation, and are therefore members of the δ Scuti class of variable stars. Others, however, are constant to less than a few thousandths of a magnitude, while still others lie outside the observed instability strip as shown in Figure 5. Table 3 is a listing of the data on all of the δ Delphini stars which have been tested for light variability. The δ Delphini stars which are δ Scuti variables all have relatively large amplitudes. Three of them, ρ Pup (HR 3185), δ Del itself (HR 7928), and δ Sct itself (HR 7020), are members of the original five stars from which Eggen (1956) announced the existence of the δ Scuti class.

TABLE 3

VARIABILITY AMONG DELTA DELPHINI STARS

HR	*P* (day)	AMPLITUDE (mag)	CONSTANCY mag	hr	SOURCE*	*v* sin *i*	SOURCE*
421.........	Var.?	...	...	...	2	...	...
1706.........	0.087	0.080	...	...	1	33	1
1974.........	Const.	...	0.003	2.6	3	80	4
2100.........	0.060	...	...	...	1	70	1
3185.........	0.141	0.100	...	...	1	14	1
3228.........	Const.	...	0.004	3.0	3	80	4
3265.........	0.097	0.040	...	...	1	25	1
4760.........	Const.	...	0.002	4.0	3	93	4
5017.........	0.135	0.35	...	...	1	17	1
7020.........	0.194	0.290	...	...	1	32	1
7928.........	0.153	0.050	...	...	1	41, 25	1, 5
7984.........	Const.	...	0.002	1.3	3	90	...

* (1) Baglin *et al.* 1973, (2) Kukarkin, Efremov, and Kholopov 1958, (3) Breger (private communication), (4) Danziger and Faber 1972, (5) personal estimate.

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f) *Summary and Discussion of the Photometry*

The preceding sections have shown that the stars classified spectroscopically as δ Delphini stars are not an astrophysically homogeneous group on the basis of *uvbyβ* photometry. We have suggested that the computed color excesses in most of the δ Delphini stars can be attributed to reddening, line blocking due to increased metallicity, uncalibrated luminosity effects, or a combination of these. We have chosen β as a temperature parameter for the δ Delphini stars because it is relatively insensitive to reddening and line blocking and because, for luminosity class IV and V A stars, temperature is a single-value function of β with very little dependence on luminosity (Breger 1974*b*).

The m_1 index indicates that some of the δ Delphini stars are metal-rich compared with the field star or, in some cases, even the Hyades main sequence, but that most δ Delphini stars have m_1 indices within the range of normal-abundance stars. We cannot conclude, however, that these δ Delphini stars with normal m_1 indices have normal abundances, since about half of the Am stars have $m_1 < 0.230$ (Milton and Conti 1968; Conti 1970), which is also within the range of normal stars.

Assuming normal masses, the calculated absolute magnitudes of the δ Delphini stars indicate that they range in luminosity from class V to class III. The faint δ Delphini stars are a much more compact group in the (β, M_v) plane than are the bright δ Delphini stars, but many of the faint δ Delphini stars have been reclassified as normal by Cowley and Cowley (1965).

Half of the bright δ Delphini stars have been tested for light variability, and six of these are known to be pulsational variables of the δ Scuti class. Several, however, are photometrically constant to a few thousandths of a magnitude, while others lie outside the present observed cool boundary of the instability strip.

Because of the inhomogeneity indicated by *uvbyβ* photometry of the stars comprising the δ Delphini class, it is unsafe to assume physical parameters for a particular star of this class based only on its spectral similarity to δ Del itself. It is certainly incorrect to assume that all δ Delphini stars are δ Scuti pulsators.

III. ROTATION, PULSATION, AND METALLICISM

Before discussing rotation in the δ Delphini stars, it is necessary to discuss the relations among rotation, pulsation, and metallicism in general for stars in the same region of the H-R diagram as the δ Delphini stars.

Figure 6 is a plot of *v* sin *i* versus amplitude of the light variability for all of the δ Scuti stars for which both of these quantities were listed by Baglin *et al.* (1973). The diagram shows a clear correlation between *v* sin *i* and amplitude: the largest amplitude δ Scuti stars all have low *v* sin *i*, while the fastest rotators all have relatively small pulsational amplitudes. It seems that slow rotation favors pulsation among the δ Scuti stars. Danziger and Faber (1972) have shown that, among the late A and early F subgiant and giant stars, the slow rotators are preferentially δ Scuti pulsators, whereas Abt (1975) has shown that virtually all of the slowly rotating A5–A9 main-sequence stars are metallic-lined. Some of the Am stars must therefore evolve into δ Scuti pulsators, and the δ Delphini stars are good candidates to have done just that. The mean rotational velocity of the bright δ Delphini stars is 53 km s^{-1}, although there is probably a selec-

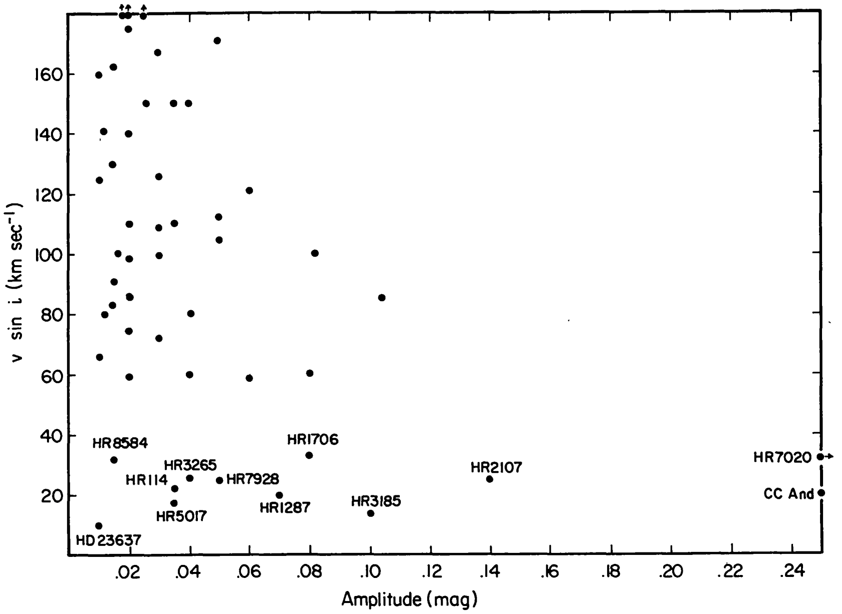

FIG. 6.—The rotational velocity versus amplitude of pulsation plot for the δ Scuti stars listed by Baglin *et al.* (1973). The correlation between these two parameters indicates that low rotational velocity is conducive to large amplitude pulsation. The low *v* sin *i* stars are labeled. Half of them are listed in Table 1 as δ Del stars.

tion effect in favor of slow rotators, as the line strength anomalies which characterize these stars are more difficult to recognize at higher rotational velocities. In Figure 6 the δ Scuti stars with $v \sin i < 40$ km s^{-1} have been identified, and a check of Table 3 shows that one-half of them are classified as δ Delphini stars. The correlation between $v \sin i$ and amplitude suggests that most of these six δ Delphini stars may be intrinsically slow rotators. Assuming normal masses and evolutionary tracks, they were probably Am stars when they were on the main sequence. That the spectra of the δ Delphini stars resemble the spectra of the classical Am stars at classification dispersion strengthens the suspicion that these pulsating subgiant and giant stars may have evolved from nonpulsating metallic-line stars. We have performed differential abundance analyses on many of the stars labeled in Figure 6 in order to test the hypothesis that such an evolutionary relation exists.

IV. ABUNDANCES OF THE SHARP-LINED, BRIGHT DELTA DELPHINI STARS

Table 4 is a list of the stars on which we have performed abundance analyses along with the adopted atmospheric parameters, rotational velocities, and classification information. Preliminary differential abundances for HR 6561 were kindly provided by Myron Smith prior to publication.

a) *The Derived Atmospheric Parameters*

Effective temperatures and gravities were initially derived using Breger's (1974*a*, *b*) calibration of the β, $b - y$, and c_1 indices. In the case of stars for which β and $b - y$ did not agree, a weighted mean was used, with β generally preferred. These temperatures and gravities were checked by fitting Edmonds, Schlutter, Wells (1967) theoretical Hγ profiles for many of the program stars. Good agreement was obtained. In the worst case, ρ Pup, where β and $b - y$ disagree, the effective temperature difference for the two parameters is about 250 K. In the cases of δ Del itself and 20 CVn, which have been analyzed by other investigators, we find that the effective temperatures derived from continuum scans, fitting of Balmer line profiles, *uvbyβ* photometry, and excitation equilibria, have a range of 300 K. From this we estimate the internal accuracy of our temperatures to be ±150 K.

Under the assumption that the photometric temperature was correct, the surface gravity was adjusted to balance the Fe ionization equilibrium to within 0.1 dex. The surface gravities derived in this manner are systematically $+0.08 \pm 0.20$ dex larger than the photometric surface gravities. We estimate our internal error in the surface gravity to be ±0.2 dex.

Since many of these stars are δ Scuti pulsators, they have variable effective temperatures and surface gravities. Baglin *et al.* (1973) indicate that the larger amplitude δ Scuti variables have effective temperature variations of $\Delta T_{\rm eff} \approx 100$ K and surface gravity variations of $\Delta \log g \approx 0.1$ dex. These variations are sufficiently small that in these abundance analyses all stars will be treated as if their atmospheres were in a steady state.

The microturbulent parameter, ξ_t, was derived by requiring that no correlation exist between the derived abundances and the equivalent widths for the Fe I lines. Values in the range $4.5 < \xi_t < 7.0$ km s^{-1} were obtained with an estimated internal accuracy of ±0.5 km s^{-1}. While these numbers are typical of the values derived for microturbulence by model-atmosphere abundance analyses of late A stars, systematic effects contribute considerably to the derived value. Smith (1973*b*) estimates that the neglect of line blanketing, the use of the Corliss-Warner oscillator strengths, low values of the damping constants, and the large equivalent width scale associated with 8 Å mm^{-1} plate material as compared with the equivalent widths derived from higher dispersion plate material, all contribute about 3–3.5 km s^{-1} to the derived microturbulent parameter. He finds further corroboration for this result (Smith 1976) by a

TABLE 4

ATMOSPHERIC DATA FOR PROGRAM STARS AND COMPARISON STANDARDS

Star Name	HR	$T_{\rm eff}$ (K)	log g (cgs)	ξ_t (km s^{-1})	$v \sin i$ (km s^{-1})	Spectral Type	Source*
44 Tau.......	1287	7150	3.4	5.0	20	F2 IV–V	2
14 Aur.......	1706	7900	3.8	5.0	33	δ Del	1
6 Mon.......	2255	7500	3.6	5.0	≤10	δ Del	4
	2557	7400	3.4	5.5	30	δ Del	4
ρ Pup........	3185	7100	3.25	6.0	14	F5 IIp	2
	3265	7450	3.75	7.0	25	F3 IIIp	2
20 CVn......	5017	7500	3.7	5.0	17	F3 III	2
ξ Ser........	6561	8000	3.9	6.8	36	δ Del	3
δ Del........	7928	7320	3.25	4.5	20	δ Del	1
28 And......	114	7500	3.5	5.5	22	A7 III, F2 V	6, 7
γ Vir........	4825	7100	4.3	5.0	27	F0 V	5
	8120	7600	2.5	5.0	20	F0 III	1
	8272	7840	3.35	6.0	20	A7 III	1

* Sources of the spectral types are: (1) Cowley *et al.* 1969; (2) Morgan and Abt 1972, (3) Malaroda 1975, (4) Cowley and Crawford 1971, (5) Hoffleit 1964, (6) Cowley and Fraquelli 1974, and (7) Conti 1970.

Fourier analysis of a line profile in the Am star 32 Aqr which yields $\xi_t = 3\ \mathrm{km\ s^{-1}}$, as opposed to $\xi_t = 9\ \mathrm{km\ s^{-1}}$ from his (Smith 1971) model-atmosphere analysis of the same star. As our analysis is quite similar to Smith's, we consider the same systematic effects to be present in our derived microturbulent parameters.

b) Data Acquisition and Reduction

For each comparison and program star, one or two IIa-O plates of reciprocal dispersion of 8 to 10 Å mm^{-1}, projected slit width of 20 μm, and widening of 0.4 to 0.8 mm were used to obtain equivalent widths. About half of the plates used were obtained by the author with the McDonald Observatory 2.7 m and 2.1 m telescopes. The rest were generously taken at the KPNO, Lick, Mount Wilson, and McDonald Observatories by Myron Smith, Michel Breger, Leonard Kuhi, Deane Petersen, and Frank Fekel. All plates were traced on the KPNO PDS microdensitometer and converted to intensities using the KPNO spectrophotometric reduction programs, SPECT1 and SPECT2, on the University of Texas CDC 6600 computer. Equivalent widths were measured treating all lines as triangles. A complete list of all the plate material used, its source, the oscillator strengths used, and the measured equivalent widths can be found in Appendix B. In addition, the derived equivalent width scales are discussed and compared internally for material from different telescopes and externally with other published equivalent widths.

Abundances were computed using convective, metal-line-unblanketed ATLAS5 (Kurucz 1970) model atmospheres with solar abundances in conjunction with the program WIDTH5 (Kurucz, private communication). Damping constants for all lines were presumed to be 10 times the value of the classical radiation damping constant. No lines on the damping portion of the curve of growth were used. We assume that errors due to incorrect oscillator strengths or damping constants are systematic and hence approximately cancel out in the differential analysis of the program stars relative to the comparison standards. We have intentionally used unblanketed models and the "old" oscillator strength scale to keep our derived abundances as close as possible to the system of Smith (1971, 1973*a*). Due to the similarity between our analysis and Smith's, the variation of abundance with temperature, gravity, and microturbulence computed and tabulated by Smith (1971) may be applied to the abundances presented in this paper.

c) The Derived Abundances

Table 5 is a listing of the log of the derived abundances on a scale of $\log \mathrm{H} = 12.00$, the number of lines of each ion measured, and the rms scatter. We estimate the internal error associated with these abundances to be ±0.1 dex for ions with many lines, such as Fe I, Fe II, and Ti II. This corresponds to the change in abundance for Fe if the effective temperature is changed by the estimated error of 150 K, with the necessary adjustment of the surface gravity to rebalance the Fe ionization equilibrium. The error in the abundance of ions for which only one or two lines were measured is estimated to be as large as ±0.5 dex, especially for abundances determined exclusively from very weak lines, such as Nd, or exclusively from strong lines lying on the flat portion of the curve of growth, such as Sr II and Ba II. The abundances of C I, S I, and Zn I have been determined from a few lines in the wavelength region 4700–4800 Å where the IIa-O plate is dropping in sensitivity and hence are less reliable than many of the other abundances. The rms scatter listed in Table 5 is not considered to be a good representation of the errors in the associated abundances as it includes the systematic effects of the errors in the oscillator strengths.

In Table 6 we compare the derived abundances for the comparison standards HR 114 and HR 4825 with the abundances derived for the same stars by Smith (1971). We find an average scatter between the two studies of ±0.16 dex. While some of this scatter is intrinsic, part of it is systematic and due to differences in effective temperature, surface gravity, and line lists used. The equivalent width scales for HR 114 from this study and Smith's study show no systematic shift, while for HR 4825 our equivalent widths are on the average 11% larger than Smith's.

In the following discussion we choose to analyze the derived abundances normalized to the Fe abundance. This will allow an easy comparison with the metallic-line star abundances, which are best represented in this form. In addition, small shifts in the effective temperature or equivalent width scale in a given star to first approximation give rise to a shift in the entire abundance scale. Because of this the normalization to Fe minimizes the effects of errors in equivalent width scale or effective temperature.

As the analyzed δ Delphini stars did not all prove to have similar abundances, we will break the discussion of them into two parts. First, we will discuss the standard star abundances and will discuss as a group HR 1706, HR 2255, HR 3265, HR 6561, and HR 7928, which have similar abundance anomalies and which will hereafter be referred to as a group as the *anomalous-abundance δ Delphini stars*. Then we will discuss the other analyzed stars on an individual basis.

V. THE ABUNDANCE ANOMALIES IN HR 1706, HR 2255, HR 3265, HR 6561, AND HR 7928

In Figure 7 the abundances normalized to Fe for HR 1706, HR 2255, HR 3265, HR 6561, and HR 7928 and the four comparison standards HR 114, HR 4825, HR 8120, and HR 8272 are plotted. The rms scatter for all ions for the relative abundances among the standard stars is ±0.12 dex. We find no significant systematic effects in the abundances of the standard stars as a function of luminosity. The internal scatter in the standard star abundances is less than the external differences found in the previous section in the comparison of the abundances of HR 114 and HR 4825 with those derived by Smith (1971).

TABLE 5

LOG OF THE DERIVED ABUNDANCES FOR COMPARISON AND PROGRAM STARS (log H = 12.00)

	HR114	HR4825	HR8120	HR8272	HR1287	HR1706
C I	8.18(2).20	7.89(2).09	7.91(3).09	8.13(3).24	-	8.16(3).24
Al I	5.08(2).04	4.43(2).00	4.66(2).16	5.19(2).07	4.80(2).20	5.05(2).29
Si II	-	7.05(2).23	7.28(2).37	7.06(1) -	8.16(1) -	7.59(2).41
S I	6.56(2).22	6.70(2).05	6.45(2).17	6.99(3).13	-	6.89(3).09
Ca I	5.95(8).19	5.59(7).24	5.50(8).28	6.01(8).28	6.07(9).22	5.99(8).26
Sc II	2.84(7).28	2.31(6).12	2.68(7).25	2.99(8).17	2.72(8).24	3.11(7).27
Ti II	4.19(30).29	3.80(35).25	4.05(34).22	4.41(34).22	4.39(35).26	4.43(38).29
V II	3.33(6).25	3.34(6).34	3.36(5).18	3.65(4).27	3.50(6).14	3.96(6).23
Cr I	4.97(13).16	4.62(11).25	4.71(8).13	5.15(6).13	5.20(7).20	5.12(12).22
Cr II	5.11(14).30	4.89(12).23	4.99(10).12	5.33(12).13	5.38(12).15	5.25(13).18
Mn I	4.40(10).29	4.38(11).38	4.40(9).44	4.99(10).25	4.82(10).25	4.79(11).37
Fe I	6.21(117).25	6.01(131).34	6.05(85).32	6.42(96).25	6.38(127).21	6.45(140).24
Fe II	6.27(21).20	5.94(24).23	6.13(23).18	6.39(26).19	6.38(22).21	6.37(27).20
Co I	4.50(3).50	4.38(3).73	4.48(2).59	4.85(3).68	4.89(3).74	4.94(3).64
Ni I	5.27(5).24	4.78(7).25	4.84(7).26	5.08(6).13	5.06(3).26	5.17(6).30
Ni II	5.05(2).05	5.26(4).35	4.76(3).10	5.32(3).18	5.07(4).24	5.18(4).23
Zn I	2.76(2).22	2.75(2).13	2.58(2).22	3.28(2).05	-	3.04(2).38
Sr II	2.87(2).12	2.81(2).12	-	3.12(2).15	3.29(2).02	3.64(2).16
Y II	2.23(6).18	2.32(5).48	2.29(4).14	2.40(6).19	2.33(7).37	2.82(5).33
Zr II	2.61(5).32	2.42(5).25	2.47(6).16	2.89(5).15	2.79(6).30	3.13(6).25
Ba II	1.69(2).08	-	1.43(2).29	1.71(1) -	1.46(1) -	2.01(2).29
La II	1.55(5).37	1.48(5).23	1.70(6).47	1.94(4).58	1.55(5).15	2.15(7).33
Ce II	1.90(6).15	1.85(6).37	1.70(6).43	2.24(4).75	1.83(6).28	2.38(7).25
Nd II	2.20(2).50	1.82(2).82	-	2.29(2).34	1.84(2).07	2.56(2).32
Sm II	1.52(1) -	1.51(2).11	1.43(1) -	1.98(1) -	1.69(2).21	2.25(2).01
Eu II	0.92(2).16	0.73(2).12	-	0.80(1) -	0.97(2).14	1.36(2).20
Gd II	-	1.12(1) -	1.37(1) -	1.81(1) -	1.56(1) -	2.09(1) -

	HR2255	HR2557	HR3185	HR3265	HR5017	HR7928
C I	8.38(2).01	8.05(2).05	7.96(2).12	8.31(2).12	8.49(2).15	8.14(3).12
Al I	5.45(2).02	4.78(2).36	5.06(2).25	4.83(2).37	5.49(2).26	4.97(2).15
Si II	8.02(2).28	7.14(1) -	8.65(2).39	7.80(1) -	8.53(2).17	7.58(2).18
S I	7.00(3).08	7.06(3).13	6.45(3).32	6.50(3).07	7.03(3).06	6.83(3).18
Ca I	6.20(8).28	5.91(6).28	6.21(8).25	5.94(7).25	6.47(7).29	5.69(8).29
Sc II	3.32(9).31	3.43(8).48	2.92(9).33	2.82(6).27	3.64(9).30	2.31(9).21
Ti II	4.61(37).31	4.45(30).30	4.51(33).30	4.20(33).20	4.92(38).28	3.95(36).28
V II	4.01(7).24	3.80(5).34	3.78(5).21	3.74(4).20	4.26(6).30	3.19(7).18
Cr I	5.30(12).22	5.19(5).22	5.36(11).09	5.09(8).30	5.62(11).15	4.67(11).16
Cr II	5.50(13).18	5.49(9).25	5.59(14).28	5.35(13).30	5.83(12).17	5.07(13).20
Mn I	5.09(11).29	4.77(11) .30	5.16(10).27	4.89(11).31	5.34(11).41	4.61(11).38
Fe I	6.69(151).25	6.46(119).37	6.72(126).26	6.49(117).26	6.98(154).26	6.13(146).24
Fe II	6.69(28).24	6.50(21).38	6.72(29).27	6.42(25).26	6.97(27).26	6.24(26).16
Co I	5.19(3).58	4.84(3).70	5.14(3).66	5.03(3).45	5.49(3).72	4.52(3).57
Ni I	5.64(8).38	5.10(5).29	5.72(7).34	5.38(8).25	5.81(7).27	4.98(6).18
Ni II	5.65(4).28	5.36(3).13	5.42(3).17	5.69(4).36	5.87(4).21	5.10(4).23
Zn I	3.63(2).02	2.51(1) -	3.61(2).08	3.35(2).06	3.58(2).06	3.23(2).05
Sr II	3.85(2).08	3.68(2).12	3.47(2).20	3.98(2).23	3.70(2).13	3.51(2).12
Y II	3.30(7).30	2.80(4).55	2.89(7).55	3.69(3).09	3.20(7).38	2.73(7).35
Zr II	3.63(6).29	2.98(4).14	3.21(5).31	3.33(5).19	3.45(5).26	2.93(5).20
Ba II	2.75(2).30	1.14(1) -	1.80(2).10	1.96(1) -	2.35(1) -	2.27(2).18
La II	2.62(8).25	2.33(5).46	2.04(7).21	2.36(8).21	2.73(8).22	1.82(7).04
Ce II	2.69(7).27	2.31(7).35	2.36(7).32	2.76(7).25	2.87(7).34	1.99(7).23
Nd II	2.58(2) .17	2.97(1) -	2.46(2).22	2.84(2).42	2.78(2).15	2.25(2).27
Sm II	2.36(2).05	2.03(2).07	2.09(2).10	2.32(2).18	2.43(2).14	1.74(2).11
Eu II	2.24(2).23	1.44(2).67	2.05(2).26	2.09(2).40	2.42(2).28	1.58(2).17
Gd II	2.37(1) -	2.14(1) -	2.09(1) -	2.14(1) -	2.41(1) -	1.70(1) -

The format of each entry in this table is the average of the log abundance derived for each ion, the number of lines measured for that ion in parentheses, and the rms scatter of the abundances.

TABLE 6

COMPARISON OF THE DERIVED ABUNDANCES FOR THE STANDARD STARS HR 114 AND HR 4825 FROM THIS STUDY AND THE STUDY OF SMITH (1971)

	HR 114		HR4825		
	THIS STUDY	SMITH(1971a)	THIS STUDY	SMITH(1971a)	AVERAGE DIFFERENCE*
C I	8.18	8.37	7.89	8.25	-0.28
Al I	5.08	4.86	4.43	4.85	-0.10
Si II	-	7.00	7.05	7.13	(-0.08)
S I	6.56	6.60	6.70	6.61	+0.03
Ca I	5.95	6.09	5.59	5.81	-0.18
Sc II	2.84	2.73	2.31	2.29	+0.07
Ti II	4.19	4.24	3.80	3.92	-0.09
V II	3.33	3.12	3.34	3.17	+0.19
Cr I	4.97	5.21	4.62	4.79	-0.21
Cr II	5.11	5.43	4.89	5.32	-0.38
Mn I	4.40	4.89	4.38	4.54	-0.33
Fe I	6.21	6.36	6.01	5.99	-0.07
Fe II	6.27	6.23	5.94	6.06	-0.04
Co I	4.50	4.90	4.38	4.52	-0.27
Ni I	5.27	5.22	4.78	5.01	-0.09
Ni II	5.05	4.96	5.26	5.14	+0.11
Zn I	2.76	2.84	2.75	2.81	-0.07
Sr II	2.87	2.72	2.81	2.57	+0.20
Y II	2.23	2.34	2.32	2.03	+0.09
Zr II	2.61	3.00	2.42	2.55	-0.26
Ba II	1.69	1.92	-	1.52	(-0.23)
La II	1.55	1.66	1.48	1.39	-0.01
Ce II	1.90	1.83	1.84	1.77	+0.07
Nd II	2.20	1.69	1.82	1.54	+0.40
Sm II	1.52	1.40	1.51	1.47	+0.08
Eu II	0.92	1.27	0.73	0.84	-0.23
Gd II	-	1.39	1.12	1.09	(+0.03)
T_{eff}(K)	7500	7700	7100	7100	
Log g(cgs)	3.5	3.5	4.3	4.0	
ξ_t(km/sec)	5.5	5.0	5.0	5.0	

* The average difference is defined as the value from this study minus the value from the study of Smith.

The δ Delphini stars plotted in Figure 7 show significant abundance anomalies (by anomaly we mean an abnormal [N/Fe] ratio). Their Fe abundances range from normal in HR 7928 to an enhancement of +0.5 dex in HR 2255 and HR 6561. The average Fe enhancement is +0.3 dex. The apparent Si II enhancement is not considered to be significant, as the Si II abundance was determined for each star from only one or two (λλ4128, 4130) partially blended, high-excitation ($\chi = 9.8$ eV) lines, and as a consequence is unreliable. All of the abundances beyond the iron-peak elements are enhanced, although the derived Eu abundance is probably too large, as we have not accounted for the effect of hyperfine splitting of the Eu lines, which acts as a pseudomicroturbulence (Hartoog, Cowley, and Adelman 1974). This effect is also unaccounted for in the metallic-line star abundances which we will compare with the program δ Delphini stars.

In Figure 8 the anomalous abundances of the five program δ Delphini stars are compared with the abundances of the main-sequence Am stars (Smith 1971) and with the abundances of five evolved Am stars, HR 1103, HR 1248, HR 5752, HR 6559, and HR 7653, lying from 1 to 2 magnitudes above the main sequence (Smith, private communication). The run of abundances for these anomalous-abundance δ Delphini stars is remarkably similar to the abundances of the evolved Am stars. The elements typically deficient with respect to Fe in Am stars, C, Ca, and Sc, are normal or only slightly deficient with respect to Fe in this group of δ Delphini stars, but we note that the evolved Am stars have on the average a less pronounced deficiency of these elements than do the main-sequence Am stars. This moderating of the deficient elements has been noted before in the case of Ca (Abt 1965; Smith 1971, 1973*c*). The rare earths are enhanced in these δ Delphini stars, although not quite as much as in the metallic-line stars. The [Sr/Fe] and [Y/Fe] abundances are quite similar to the Am stars, while the [Zr/Fe] abundance for these δ Delphini stars is similar to the evolved Am stars,

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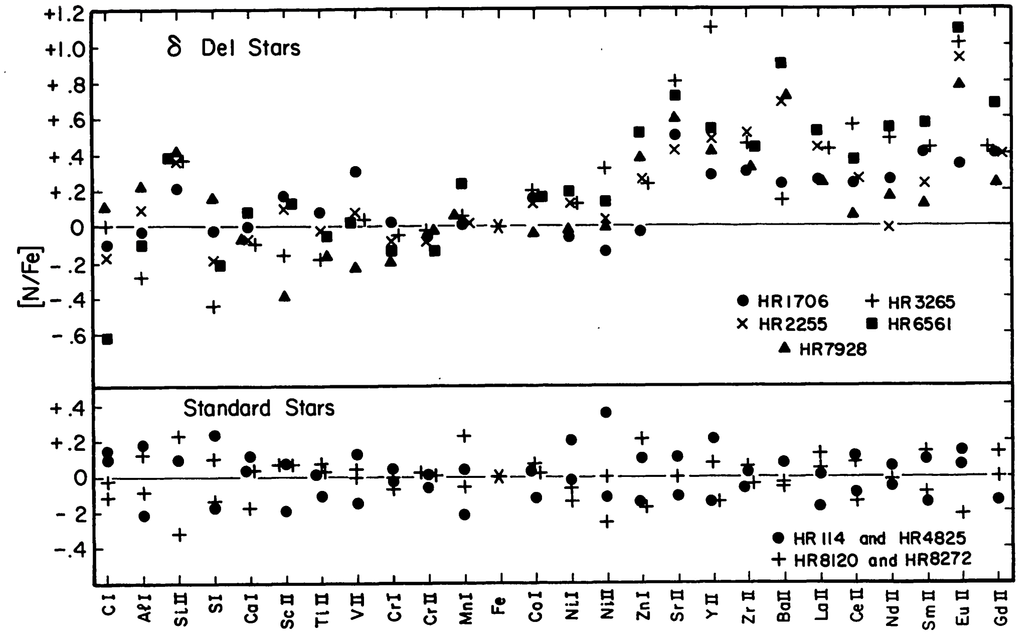

FIG. 7.—The derived abundances normalized to Fe in the anomalous-abundance δ Delphini stars and in the four comparison standard stars. The standards have been separated into two groups according to surface gravity to show that their abundances are not dependent on luminosity.

but is high compared with the main-sequence Am stars. The [Zr/Fe] ratio appears to become more enhanced with increasing luminosity in the metallic-line stars (Smith 1973*c*), and again, as in the deficient elements, these anomalous-abundance δ Delphini stars are similar to the evolved Am stars.

Smith (1971) showed that the anomalous [N/Fe] ratios in the metallic-line stars in general do not vary by more than a factor of 2, even though the [Fe/H] ratio in these stars ranges over a factor of 5. That is, in the Am stars the element abundances, [N/H], are strongly coupled to the [Fe/H] abundance. This same effect is present in the five δ Delphini stars under discussion here. The well-determined abundances of Ca I, Sc II, Ti II, Cr I, Cr II, Mn I, Y II, and Zr II all show less scatter when normalized to the Fe abundance than does the Fe abundance itself.

The abundances of [Ca/Fe], [Sc/Fe], and [Zr/Fe] are all similar to those of the evolved Am stars but not those of the main-sequence Am stars. We argued earlier, for statistical reasons, that the slow rotation for these δ Delphini stars is intrinsic and, as a

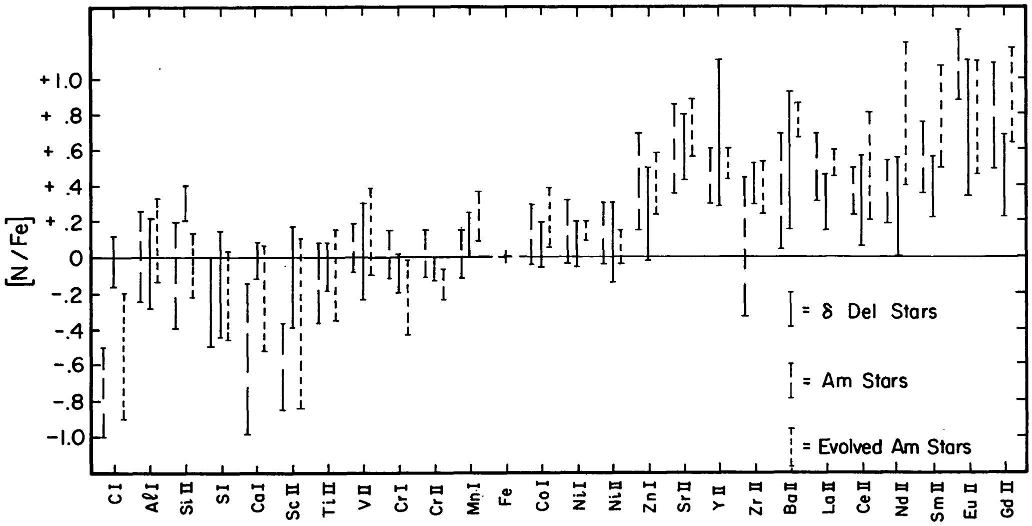

FIG. 8.—A comparison of the abundances normalized to Fe in the anomalous-abundance δ Del stars with those in the Am stars (Smith 1971) and those in five evolved Am stars lying from 1 to 2 mag above the main sequence (Smith, private communication). This diagram shows the anomalous-abundance δ Del stars to be very similar to the evolved Am stars rather than to the main-sequence Am stars. Note especially the Ca I, Sc II, and Zr II abundances.

consequence, they were probably Am stars when they were on the main sequence because slow rotation is thought to be a sufficient condition for metallicism in the Am domain (Abt and Moyd 1973). This, coupled with the present abundance analyses of HR 1706, HR 2255, HR 3265, HR 6561, and HR 7928 and their positions in the H-R diagram, suggests that they are probably evolved metallic-line stars. Abundance analyses of one of the evolved Am stars plotted in Figure 8, 15 Vul, have been previously performed by Miczaika *et al.* (1956) and by Farragiana and van't Veer-Menneret (1971), as well as by Smith (private communication). These studies show 15 Vul to have marginal Am characteristics. In particular, Smith finds [Ca/Fe] = −0.09 and [Sc/Fe] = −0.26, along with similar overabundances of [Sr/Fe], [Y/Fe], and [Zr/Fe]. While this star has been reclassified A4 III (marginal Am?) by Cowley *et al.* (1969), we point out that it has in the past been classified as Am (Slettebak 1949), and that its abundances are indistinguishable from the abundances of the anomalous-abundance δ Delphini stars.

We have also compared the anomalous-abundance δ Delphini stars with several other groups of peculiar stars. They do not appear to be similar to the Ap stars. They do not have the large overabundance of Mn associated with the Hg-Mn stars, and Y is enhanced with respect to Fe rather than deficient as in the Sr-Cr-Eu Ap stars (Adelman 1973). Figure 9 compares the anomalous-abundance δ Delphini stars with the Ba stars (Warner 1965), and shows many similarities between the two classes. The Fe abundance in the Ba stars is enhanced by 0.15 dex, which may not be significant. The only element for which the abundance plotted in Figure 9 is very different between the two groups is Eu, and we feel this difference may not be significant. The Eu abundance is too large in the δ Delphini stars due to the previously mentioned effect of the neglect of hyperfine splitting, and the Eu abundance in both groups is quite uncertain as only one or two lines were measured for each star.

Probably a real difference between the Ba stars and the δ Delphini stars which is not apparent in Figure 9 is the C abundance. [C/Fe] seems to be normal in the δ Delphini stars, whereas Warner inferred from the strength of the C_2, CH, and CN bands that it is overabundant in the Ba stars by a factor of 2 to 5 times. This overabundance of C, along with the other abundance anomalies in the Ba stars, is thought to be relatively well understood in terms of *s*-processed core material being circulated to the surface during a carbon-burning evolutionary stage. Assuming normal evolutionary tracks, the δ Delphini stars are in a stage of hydrogen burning during which there is no known mechanism for circulating core material to the surface, and during which significant *s*-processing is probably not possible as $^{14}N(n, p)^{14}C$ is expected to absorb most of the free neutrons that may be generated.

We conclude that the mechanisms which give rise to the similar abundance patterns for the measured elements in the anomalous-abundance δ Delphini stars and the Ba stars must be different in origin, and the apparent similarity between the two groups is coincidental. The difference in C abundance, the lack of an *s*-process, core-to-surface circulation mechanism during hydrogen burning, and the Fe enhancement of 0.5 dex in HR 2255 and HR 6561, all support this thesis. The Ba stars show no large overabundances of Fe, and theoretically cannot do so, as the iron-peak elements are the *s*-process seed nuclei necessary for generating the observed overabundances of the heavier elements.

a) *HR 3265*

The [Y/Fe] abundance anomaly for HR 3265 of +1.1 dex shown in Figure 6 is significantly larger than the [Y/Fe] anomalies of the other anomalous-

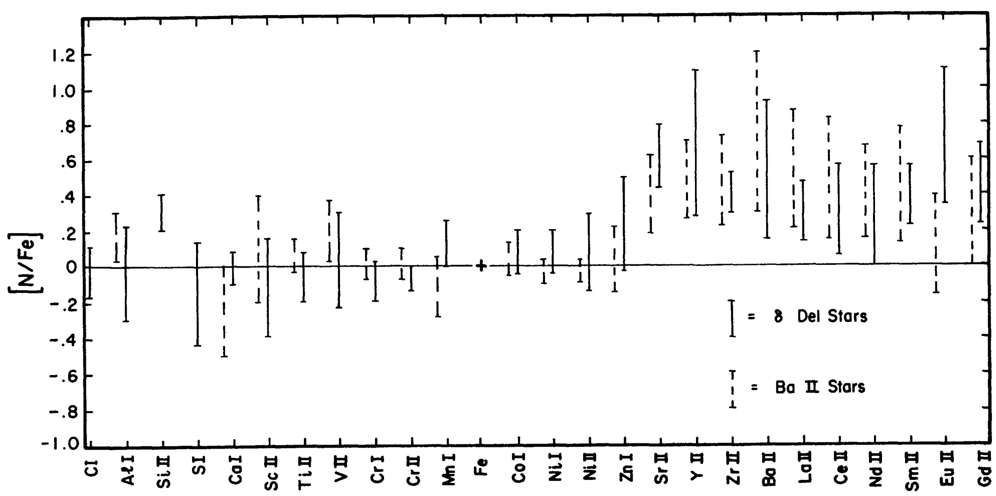

FIG. 9.—Comparison of the abundances normalized to Fe in the anomalous-abundance δ Del stars and the Ba II stars (Warner 1965) showing striking similarities between the two groups. See the text for arguments that the similarities are coincidental.

abundance δ Delphini stars. We consider this unusually large enhancement to be real. It is even apparent in a visual inspection of the spectrum of HR 3265 and has been previously noted by Smith as cited in Baglin *et al.* (1973).

b) *HR 7928, δ Delphini*

Four previous abundance analyses are available in the literature for δ Del itself. In Table 7 we compare the present abundances with those derived by Bessell (1969), Breger (1970), Reimers (1969), and Ishikawa (1973), along with the abundances derived from a reanalysis of Ishikawa's data relative to our standards. Our equivalent widths for HR 7928 are determined from two plates, a McDonald Observatory 2.7 m telescope 8 Å mm^{-1} plate and a KPNO 2.1 m telescope 8.9 Å mm^{-1} plate which are in excellent agreement with each other. Nevertheless, the equivalent widths from these two plates are systematically about 20% less than the equivalent widths derived independently by Bessell, Reimers, and Ishikawa, which are basically in agreement with each other. We can offer no explanation for this discrepancy, but note that its effect is mostly canceled out for the abundances normalized to Fe.

Reimers's analysis was done with respect to the Sun, using solar *gf* values for some ions and absolute *gf* values for others. Our abundances disagree significantly for four of the five ions for which he used absolute *gf* values, and we suspect that this difference in oscillator strengths is the reason. In addition, the

TABLE 7

COMPARISON OF THE ABUNDANCES FROM DIFFERENT STUDIES OF DELTA DELPHINI

	[N/Fe]					
	THIS STUDY	BESSELL (1969)	BREGER (1970)	REIMERS (1969)	ISHIKAWA (1973)	ISHIKAWA*
C I	.11			-.33	-.04	-.13(1)
Al I	.12			-.16		
Si II	.42			-.16	-.21	
S I	.15					
Ca I	-.08	-.32	-.23	-.13	-.14	.03(9)
Sc II	-.40	-.42	-.35	-.08	.04	-.40(5)
Ti II	-.17	-.09	-.26	-.12	.53	-.14(23)
V II	-.24			-.18	.49	-.42(4)
Cr I	-.20	.46	-.08	-.05	.29	.03(7)
Cr II	-.02	.11	-.11	-.03	.19	-.14(11)
Mn I	.06			-.04	-.13	.09(6)
Co I	-.04			.03	.44	-.40(1)
Ni I	-.02			.29	.04	.28(5)
Ni II	-.01					
Zn I	.38			.22	.50	.40(2)
Sr II	.60			.11	.71	.25(1)
Y II	.41			.59	.99	.15(2)
Zr II	.32			.54	1.29	.27(3)
Ba II	.72			.09	.84	.43(1)
La II	.14			.33	.56	-.14(2)
Ce II	.06				1.24	-.27(1)
Nd II	.17					
Sm II	.12					
Eu II	.78			.45	1.52	.55(1)
Gd II	.24					
[Fe/H]	.00	normal	-.25	-.19	-.19	.21
T_{eff}(K)	7320	7200	6950	7100	7200	7320
Log g(cgs)	3.25	3.6	3.2	3.8	3.6	3.25
ξ_t(km/sec)	4.5	4.2	4.3	7.0	4.0	4.5
Comparison Stars	HR114 HR4825 HR8120 HR8272	η Lep	η Lep α CMi	Sun	Sun	HR114 HR4825 HR8120 HR8272
Analysis	fine	coarse	fine	fine	fine	fine

* Abundances derived from the data from Ishikawa's study rerun on our system and compared with our standard stars. The numbers in parentheses represent the number of lines used for each ion.

discrepancies for Si II, Sr II, and Ba II are at least partially due to the different microturbulent velocities used, as those abundances are derived from a few strong lines lying on the flat portion of the curve of growth. It is less clear why Sc II and Ni I give disparate abundances, and as Reimers's line list is quite different from ours, we did not feel that deriving abundances from the small number of data in common would provide any understanding of the discrepancies.

Ishikawa's analysis was also done with respect to the Sun, using the most recent *gf* values available. While the atmospheric parameters used in this analysis and Ishikawa's are similar and the trend of abundances beyond the iron peak is similar, the actual numerical abundances are quite different. In order to resolve this difference, we have reanalyzed Ishikawa's data relative to our standards, using only the lines from his list which are in common with ours. The results are basically in good agreement with our abundances. The difference in the [Fe/H] ratio is attributable to the difference in the equivalent width scales. We are also in agreement for the five ions in common with Breger's (1970) model-atmosphere reanalysis of Bessell's (1969) data. Breger's lower [Fe/H] ratio is due to the lower effective temperature he used.

There are some large differences in some of the derived abundances in the different analyses of HR 7928 listed in Table 7, which makes all of the abundances seem suspect. Nevertheless, we feel that the internal consistency of the abundances of our standards, the general agreement of the present abundances of HR 7928 with those of Breger and Ishikawa's reanalyzed data, and the similarity of the abundances of the five δ Delphini stars HR 1706, HR 2255, HR 3265, HR 6561, and HR 7928, all make the run of abundances which we derived in HR 7928 (and, by implication, the other stars analyzed) believable. In particular, in HR 7928 we feel that the [Sc/Fe] deficiency is real, and the marginal deficiencies of [Ti/Fe], [V/Fe], and [Cr/Fe] may also be real. Sr, Y, Zr, and the rare earths are all enhanced relative to Fe.

VI. THE ABUNDANCES OF HR 1287, HR 2557, HR 3185, AND HR 5017

Three of the δ Delphini stars analyzed, HR 2557, HR 3185, and HR 5017, and the F2 IV–V δ Scuti star analyzed, HR 1287, do not have readily discernible abundance anomalies ([N/Fe] ratios), although the metallicity, [Fe/H], of the δ Delphini stars is high. The derived abundances normalized to Fe and the atmospheric parameters adopted are given in Table 8.

TABLE 8

ABUNDANCES NORMALIZED TO Fe AND THE ADOPTED ATMOSPHERIC PARAMETERS IN THE STARS HR 1287, HR 2557, HR 3185, AND HR 5017

	HR1287	HR2557	HR3185	HR5017
C I	-	-.28	-.61	-.33
Al I	-.24	-.36	-.32	-.15
Si II	.81	-.31	.96	.58
S I	-	.08	-.77	-.44
Ca I	.10	-.16	-.09	-.09
Sc II	-.19	.42	-.33	.14
Ti II	.07	.03	-.15	.01
V II	-.12	.08	-.18	.07
Cr I	.13	.02	-.05	-.04
Cr II	.10	.11	-.03	-.05
Mn I	.07	-.07	.07	.00
Co I	.13	-.01	.04	.14
Ni I	-.14	-.20	.18	.02
Ni II	-.23	-.04	-.22	-.03
Zn I	-	-.63	.22	-.06
Sr II	.18	.47	.02	.00
Y II	-.18	.19	.04	.09
Zr II	-.01	.08	.07	.05
Ba II	-.29	-.71	-.29	.01
La II	-.32	.36	-.17	.26
Ce II	-.29	.09	-.10	.15
Nd II	-.44	.59	-.16	-.09
Sm II	-.12	.12	-.06	.02
Eu II	-.02	.35	.72	.83
Gd II	-.10	.38	.09	.16
[Fe/H]	0.20	0.30	0.54	0.80
T_{eff}(K)	7150	7400	7100	7500
log g(cgs)	3.4	3.4	3.25	3.7
ξ_t(km/sec)	5.0	5.5	6.0	5.0

a) *HR 1287, 44 Tauri*

As has been previously shown in Figure 6, half of the low $v \sin i$ large-amplitude δ Scuti variables are classified spectroscopically as δ Delphini stars. HR 114, one of our standard-abundance stars and one of the standards used by Smith (1971), is the only member of this group which has been shown to be spectroscopically normal by abundance analysis. HR 1287 is an F2 IV–V star (Morgan and Abt 1972) among this group with $v \sin i = 20 \text{ km s}^{-1}$ and a pulsational amplitude of 0.07 mag. Our analysis of this star confirms that spectroscopically normal stars can exist in the low $v \sin i$, high-amplitude sector of Figure 6. The Fe abundance lies within the range of Fe abundance for the standard stars. The large apparent overabundance of Si II is not significant, as this abundance was determined from one partially blended line. There is a trend in the abundances of Ni and the heavier elements for the [N/Fe] ratio to be low, but there is no apparent pattern to these deficiencies and we do not consider the numbers to be meaningfully different from the standards.

b) *HR 2557*

HR 2557 is classified δ Delphini by Cowley and Crawford (1971), while Morgan and Abt (1972) classify it A9 III. Crawford has calibrated M_v for $\delta c_1 < 0.28$ mag for A and early F stars, and an *extrapolation* of that calibration indicates that HR 2557 lies about 3.4 mag above the main sequence. The effective temperature and surface gravity derived for this star using Breger's calibration (1974*a*, *b*) of $b - y$, β, and c_1 are in good agreement with the excitation and ionization equilibrium for Fe. We have recently discovered this star to be variable, and a detailed analysis of this variability is in progress. The abundances of HR 2557 seem to be marginally abnormal in a manner similar to the previously discussed anomalous-abundance δ Delphini stars. The

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[Fe/H] abundance may be slightly enhanced, as may be the [N/Fe] ratio for the rare earths. The apparent deficiencies of [Zn/Fe] and [Ba/Fe] are determined from a single line each and thus are suspect. We feel the normality or abnormality of this star is still open to question.

c) *HR 3185, ρ Puppis*

HR 3185, ρ Pup, is one of the worst examples of stars for which the $b - y$, $(b - y)_0$, and β temperature indices disagree. Breger's calibration of $b - y$, c_1 yields $T_{\rm eff} = 6850$ K, $\log g = 3.5$ for this star, while his calibration of β, c_1 yields $T_{\rm eff} = 7100$, $\log g = 3.9$. We have derived abundances for ρ Pup using the higher temperature, which is in better agreement with the Fe excitation equilibrium, and find that the Fe ionization equilibrium yields a surface gravity 0.65 dex lower than the photometrically derived gravity. These discrepancies between the predicted effective temperatures and surface gravities from the *uvbyβ* photometric indices may be due to line blanketing, reddening, or uncalibrated luminosity effects as previously discussed in § II.

In Table 9 we compare our derived abundances for ρ Pup with three other studies of this star. The [Fe/H] abundance is enhanced, but the [N/Fe] ratios of the elements heavier than Fe are all normal, with the possible exception of [Eu/Fe]. Using the curve-of-growth corrections for the effects of hyperfine splitting in Eu λλ4130, 4205 (Hartoog, Cowley, and Adelman 1974), we reduce the [Eu/Fe] ratio to about +0.4 dex. Since this abundance is determined from only two lines and the other rare earths do not show similar overabundances, we cannot interpret the Eu abundance as abnormal. Among the lighter elements the C I, Al I, Si II, and S I abundances are all poorly determined. The Ca I, Sc II, the well-determined Ti II, and V II abundances all appear to be slightly deficient when normalized to Fe in all of the abundance analyses. Even though the apparent deficiencies of these elements are small, the agreement among the different analyses indicates that the effect might be real. HR 3185 has slightly enhanced [Fe/H] and possibly some mild deficiencies among the lighter elements when normalized to Fe.

TABLE 9

COMPARISON OF THE ABUNDANCES NORMALIZED TO Fe FOR HR 3185 FROM VARIOUS STUDIES

	THIS STUDY	GREENSTEIN ET AL. (1948)	BESSELL (1969)	BREGER (1970)
C I	-.61			
Al I	-.32			
Si II	.96			
S I	-.77			
Ca I	-.09	-.32	-.54	-.25
Sc II	-.33	-.96	-.44	-.32
Ti II	-.15	-.22	-.08	-.19
V II	-.18	-.36		
Cr I	-.05	.07	-.15	-.05
Cr II	-.03	-.11	.14	-.08
Mn I	.07	-.24	.09	-.13
Co I	.04	-.43		
Ni I	.18	.43		
Ni II	-.22	.26		
Zn I	.22	.38		
Sr II	.02	-.03		
Y II	.04	.21		
Zr II	.07	-.30		
Ba II	-.29	.03		
La II	-.17	-.21		
Ce II	-.10			
Nd II	-.16	{rare earths = -.20		
Sm II	-.06			
Eu II	.72	.63		
Gd II	.09			
[Fe/H]	0.54	0.17	0.36	0.42
$T_{\rm eff}$(K)	7100	-	6800	7000
log g(cgs)	3.25	2.5	3.2	3.3
ξ_t(km/sec)	6.0	-	6.6	6.0
Comparison	HR114	sun	η Lep	η Lep
Stars	HR4825			α CMi
	HR8120			
	HR8272			
Analysis	fine	coarse	coarse	fine

d) *HR 5017, 20 Canum Venaticorum*

HR 5017, 20 CVn, has been analyzed previously with respect to the Sun by Dickens *et al.* (1971) and Ishikawa (1975). We have reanalyzed the data of Ishikawa which are in common with ours, and the results of all these analyses are listed in Table 10. Ishikawa's abundances normalized to Fe look very similar to the anomalous-abundance δ Delphini stars, but in the comparison of his data run on our system with respect to our standard stars, these anomalies disappear. We consider the abundance ratios, [N/Fe], from this study, from Dickens *et al.*, and from Ishikawa's reanalyzed data to be in basic agreement and conclude that 20 CVn shows no abundance anomalies. The apparent overabundance of Si II is suspect as in the other stars analyzed in this study. If we correct the [Eu/Fe] ratio for the effect of hyperfine splitting, we still find [Eu/Fe] = 0.65. Again, as in HR 3185, this abundance is determined from only two lines and is not accompanied by similar overabundances of the other rare earths, so we do not consider it necessarily anomalous.

The [Fe/H] abundance in HR 5017 is enhanced. Dickens *et al.* (1971) concluded, from their derived abundance, [Fe/H] = 0.44 dex, that the star has metal abundances similar to those of the Hyades. We find [Fe/H] = 0.80 dex, which is a higher metallicity than for the Hyades, and Ishikawa's reanalyzed data give a similar [Fe/H] = 0.67 dex. The equivalent width scales of these studies are not in agreement, however. The abundances in this study are derived from the equivalent widths from two McDonald Observatory 2.1 m telescope 8.6 Å mm^{-1} plates which are in excellent agreement with each other, and from one KPNO 2.1 m telescope 8.9 Å mm^{-1} plate which has a slightly larger equivalent width scale. We have adopted the lower scale of the McDonald plates. Our equivalent widths are 23% larger than Ishikawa's which were measured from Okayama Observatory 1.9 m telescope 4 Å mm^{-1} plates. This is typical of

TABLE 10

Comparison of the Abundances Normalized to Fe for HR 5017 from Various Studies

	THIS STUDY	DICKENS ET AL. (1971)	ISHIKAWA (1975)	ISHIKAWA*
C I	-.33		-.30	-.46(1)
Al I	-.15		.13	.53(2)
Si II	.58	.18		
S I	-.44		-.04	-.40(2)
Ca I	-.09	-.12	.13	-.13(7)
Sc II	.14	.23	.24	-.12(7)
Ti II	.01	.23	.37	-.09(19)
V II	.07	.09	.38	
Cr I	-.04	.11	.21	-.03(1)
Cr II	-.05	-.02	.09	
Mn I	.00	-.12	.07	
Co I	.14	.16	.37	-.49(1)
Ni I	.02	.01	.07	.08(5)
Ni II	-.03			
Zn I	-.06		.35	.11(2)
Sr II	.00	.12	.57	-.04(2)
Y II	.09	.28	.19	-.44(1)
Zr II	.05	-.31	.49	-.30(1)
Ba II	.01	.31	.70	.14(1)
La II	.26	-.26	.23	.05(1)
Ce II	.15	.03	.55	
Nd II	.09			
Sm II	.02			
Eu II	.83		.87	.30(1)
Gd II	.16			
[Fe/H]	0.80	0.44	0.33	0.67
T_{eff}(K)	7500	7520	7875	7500
log g(cgs)	3.7	4.1	3.8	3.7
ξ_t(km/sec)	5.0	2.0	3.5	4.0
Comparison Stars	HR114 HR4825 HR8120 HR8272	sun	sun	HR114 HR4825 HR8120 HR8272

* Abundances derived from the data from Ishikawa's study rerun on our system and compared with our standard stars. The numbers in parentheses represent the number of lines used for each ion.

the difference in equivalent widths usually found between dispersions of 8.6 Å mm^{-1} and 4 Å mm^{-1} (cf. Smith 1973*b*). Our equivalent widths are 43% larger than those of Dickens *et al.* measured from Mount Wilson 2.5 m telescope 6.8 Å mm^{-1} plates, which is not typical and for which we have no explanation.

The difference in the [Fe/H] abundance between this analysis and Ishikawa's reanalyzed data is entirely due to the difference in the respective equivalent width scales. This difference is probably attributable to the differing spectral dispersions used. Since the abundances in this analysis are with respect to standard-star abundances derived from plates of similar dispersion, we consider that the derived metallicity of HR 5017, [Fe/H] = 0.80 dex, is correct to within an estimated internal error of ±0.2 dex, although some decrease in this ratio is expected due to differential line blanketing between HR 5017 and the four standard stars. The metallicity index, $\delta m_1 = -0.035$, for this star is in excellent agreement with our [Fe/H] ratio according to the calibration of [Fe/H] with respect to β and m_1 for Am stars (Rydgren and Smith 1974).

VII. DUPLICITY AMONG THE BRIGHT δ DELPHINI STARS

In Table 11 we list five δ Delphini stars which are known to be binary and one which is thought to be. Most of the others have not been tested yet for duplicity, so it is not possible to make a statement about the binary incidence for the group as a whole. Subdividing the class, we note from Table 11 that three of the five anomalous abundance δ Delphini stars, HR 1706, HR 6561, and HR 7828, are known to be short-period binaries. This is consistent with the interpretation that these stars are evolved metallic-line stars, most of which are binary (Abt 1961; Conti and Barker 1973). We are presently engaged in a program to determine the binary frequency among the bright δ Delphini stars.

VIII. DISCUSSION

We have suggested that the anomalous abundance δ Delphini stars, HR 1706, HR 2255, HR 3265, HR 6561, and HR 7928, are evolved metallic-line stars on the basis of their abundances, position in the (β, M_v) plane, rotational velocity, and binary incidence. Three of these five stars, HR 1706, HR 3265, and HR 7928, are also δ Scuti pulsators. The other two have not been tested for pulsation.

What is the explanation for the anomalous-abundance δ Delphini stars which seem to be evolved metallic-line stars and δ Scuti pulsators both? There are several possibilities: (i) the suggestion that the anomalous-abundance δ Delphini stars are evolved Am stars may be incorrect, i.e., the abundance anomalies in these δ Delphini stars may arise from a different mechanism than the abundance anomalies in the Am stars; (ii) each of the pulsating anomalous-abundance δ Delphini stars may be a binary consisting of an Am star and a δ Scuti star; (iii) diffusion and pulsation may be able to coexist in a single star under some conditions; or (iv) the diffusion hypothesis may not be the correct explanation for the abundance anomalies of the metallic-line stars. We discuss each of these possibilities below.

If the δ Delphini stars are not evolved Am stars, then there must be two mechanisms for producing

TABLE 11

Binaries Among the Delta Delphini Stars

HR	P (days)	$\mathcal{M}_2/\mathcal{M}_1$	$f(\mathcal{M})$	Source
1706.....	3.789	...	0.004	Harper 1934
2100.....	2.74050	...	0.060	Nadeau 1952
4760.....	Perhaps binary	...	...	Frost *et al.* 1929
6561.....	2.292285	...	...	Young 1911
7928.....	40.58	~1	...	Preston (private communication)
8322.....	1.022768	...	0.037	Batten 1961

very similar abundance anomalies in the δ Delphini stars and in the metallic-line stars. We have already rejected the *s*-process mechanism thought to produce the abundance anomalies in the Ba II stars as the source of the anomalous abundances in the δ Delphini stars. Van den Heuvel (1968*a*, *b*) suggested that the Am stars were originally secondary components in binary systems in which the primary evolved and transferred nuclear processed material onto the secondary, which then became Am. This was rejected for the Am stars because they are found in young clusters (Conti 1967; Conti and Strom 1968; Smith 1972*a*), because Am stars exist in double-line spectroscopic binaries in which the secondary is not a white dwarf, because such a process should not produce the abundance deficiencies of C, Ca, or Sc observed in Am stars, and because the Am stars form a natural continuance of the main-sequence binary frequency. The first objection cannot be applied to the δ Delphini stars. None of the anomalous-abundance δ Delphini stars are in clusters, so we can place no age constraint on them in that manner. Preston (private communication) reports that δ Del itself is a double-line spectroscopic binary (for 4 days out of its 40.58 day period) with nearly identical components. Since the presence of a third close, undetected, evolved component in this system seems unlikely, and since Sc is deficient in δ Del itself, we reject the mass transfer hypothesis for δ Del itself and also for the anomalous-abundance δ Delphini stars as a group.

Brancazio and Cameron (1967) suggested that surface nuclear spallation reactions could be responsible for the observed abundance anomalies in the magnetic Ap stars, but Adelman (1973) has argued that this mechanism could be at best only partially responsible for the observed anomalies in the Sr-Cr-Eu Ap stars. Such reactions require large magnetic fields which are present in the cool Ap stars. The magnetic nature of the δ Delphini stars has not been investigated. We can, however, rule out surface spallation reactions as the source of the anomalous abundances in the δ Delphini stars on the basis of the observed abundance pattern. Brancazio and Cameron predict that such reactions should probably enhance Sc relative to Si and enhance Cr and Mn relative to Fe for α bombardment, or should deplete Fe, Co, and Ni and produce an odd-even effect in the run of abundances for pure proton bombardment. None of these abundance relations are observed in the δ Delphini stars.

Havnes and Conti (1971) proposed a magnetic accretion model for the Sr-Cr-Eu Ap stars which, as was later argued by Adelman (1973), is untenable on the basis of the observed abundances in those Ap stars. It does, however, predict a similar overabundance of Si and the iron-peak elements, a greater overabundance of Sr, Y, and Zr, with perhaps Sr and Y being enhanced more than Zr, and an even larger enhancement of the rare earths. These abundance predictions are qualitatively similar to the observed abundance patterns in the anomalous-abundance δ Delphini stars. We consider magnetic accretion to be unlikely for the δ Delphini stars because (i) if the δ Delphini stars are magnetic, then the mechanism operating in the Ap stars should also be present in the δ Delphini stars, producing Ap-type abundances which are not observed; and (ii) many of the magnetic Ap stars are spectrum variables, whereas none of the δ Delphini stars is known to be. A Zeeman analysis of the spectra of most of the δ Delphini stars is not possible due to their relatively high rotational velocities, but could be done on a few of the slowest rotators. Such an analysis would provide a very strong test of the magnetic accretion hypothesis, as the lack of magnetic fields would rule it out and the presence of magnetic fields would show the δ Delphini stars to be significantly different from the metallic-line stars which have no measurable fields.

The star 32 Vir, a reportedly pulsating classical Am star, has been shown to be a binary in which the primary is a stable Am star and the secondary a normal-abundance δ Scuti pulsator (Kurtz *et al.* 1976). A similar explanation for the anomalous-abundance δ Delphini stars is very attractive since at least three of them are binary and it eliminates the need to explain how a star can be metallic-lined and also pulsate. Unfortunately, this hypothesis is probably not tenable for the δ Delphini stars. In none of our 8–10 Å mm^{-1} spectra of these δ Delphini stars is there any indication of line doubling. As has been mentioned, δ Del itself is an SB2 system in which both components are δ Scuti pulsators. The [Sc/Fe] deficiency in δ Del itself is difficult to explain with this model, and, finally, one of the properties of such a system should be different radial velocity curves for the metallic lines and the Ca II K line, as the Am star would dominate the metallic-line spectrum while both components would contribute to the Ca II K line, as is the case for 32 Vir. We tested for this effect in 13 δ Delphini stars on 24 8–10 Å mm^{-1} plates by measuring radial velocities from those plates using the KPNO Grant measuring machine. In no case was the K line velocity significantly different from the metal-line velocity. We therefore reject the Am– δ Scuti star binary hypothesis as a model for the anomalous-abundance δ Delphini stars.

We are left with the choice that either (i) diffusion is a much stronger phenomenon than previously thought and can exist in a pulsating star, or (ii) diffusion is not the correct theoretical explanation of the Am phenomenon. We prefer the first alternative because of the success of the diffusion hypothesis in explaining the observed properties of the metallic-line stars. The second is tantamount to the null hypothesis for the Am stars.

Where do the high-metallicity, but non–anomalous-abundance, δ Delphini stars, HR 2557, HR 3185, and HR 5017, fit into the above scheme? HR 2557 could be interpreted as having transition abundances between the anomalous-abundance δ Delphini stars and normal stars, and HR 3185 and HR 2557 are the most luminous, and therefore probably the most evolved, of the δ Delphini stars. It is tempting, therefore, to postulate that these three stars are representative of the last phase of the transition of metallic-line stars into normal stars. They are, however, interpretable as having abundances within the cosmic scatter of metallicity for normal stars. This is certainly true for HR 2557 and HR 3185. While for HR 5017 our metallicity is too high to be in the range of normal stars, other investigators (Dickens *et al.* 1971) found a Hyades-type metallicity for this star. The unusual abundances for these three stars, coupled with the similarity of HR 3185 and HR 5017 to the anomalous abundance δ Delphini stars HR 1706, HR 3265, and HR 7928 in their rotational velocity and pulsational amplitude and in their position in the (β, M_v) plane, suggest that all of these stars may have a common origin.

IX. SUGGESTIONS CONCERNING THE RELATIONSHIP BETWEEN METALLICISM AND PULSATION

We have in the previous section stated our preference for retaining the diffusion hypothesis as a working model for the Am stars, and we have suggested that the pulsating anomalous-abundance δ Delphini stars are evolved Am stars in which pulsation and metallicism coexist. We propose the following diffusion model to explain the relationship between metallicism and pulsation.

Following the suggestion of Watson (1971) and Smith (1971, 1973*a*), we propose that diffusion occurs in the radiative zone between the H I, He I, and He II ionization zones in the Am stars. This qualitatively predicts the run of abundances observed in the Am and Fm stars, especially the [Ca/Fe] and [Sc/Fe] deficiencies. Following Breger (1972), Baglin (1972), and Vauclair *et al.* (1974), we suggest that helium is sufficiently depleted from the He II ionization zone to inhibit pulsation, thus accounting for the observed exclusion between the classical Am stars and the δ Scuti pulsators. This also serves to reduce the convective overshoot from the He II ionization zone into the overlying radiative zone, thus mitigating the objections of Latour *et al.* (1975) to diffusion occurring in this zone. We further suggest that the helium depletion in the He II ionization zone is not sufficient to eliminate convection in that zone. This provides a convective barrier between the upper and lower radiative zones so that the Am anomalies can arise quickly from diffusion in the upper radiative zone and then remain essentially time-independent during the main-sequence lifetime of the Am star as required by the observations (Smith 1972*a*, 1973*a*). Enough helium remains in the He II ionization zone that pulsational instabilities can grow in an Am star as it evolves into the giant region as is required by the evidence presented in this paper that some Am stars evolve into δ Scuti pulsators. The pulsating anomalous-abundance δ Delphini stars are examples of these evolved Am stars in which either (i) diffusion occurs below the He II ionization zone where the pulsational amplitude becomes small due to the increasing density, or (ii) mixing across the upper radiative zone is a slow enough process that these δ Delphini stars represent evolved Am stars in which diffusion no longer occurs but for which mixing has not yet eliminated the apparent surface anomalies.

Pulsation and metallicism may coexist in other border regions of the Am domain. Abt (1975) has shown that while rotation, temperature, and age are sufficient to determine if a star will be metallic-lined or not, they are insufficient to determine the strength of metallicism in a given metallic-line star. Some other factor or factors are involved, and we have hypothesized that pulsation may be one of them. We are presently in the process of testing all of the marginal Am stars for pulsation, and have found two so far, HR 4594 and HR 8210, which do pulsate.

In summary, we propose that (i) classical Am stars do not pulsate, (ii) metallicism and pulsation can coexist among the subgiant and giant A and F stars as in the anomalous-abundance δ Delphini stars, and (iii) pulsation and metallicism may coexist among the marginal (Am:) metallic-line stars.

I would like to express my sincere thanks to Dr. Michel Breger, who suggested and supervised this work, for his continued guidance and help. I am equally grateful to Dr. Myron Smith for many enlightening discussions and for very generously provided unpublished abundances of HR 6561 and five evolved Am stars. Thanks are due to Drs. Myron Smith, Michel Breger, Leonard Kuhi, Deane Petersen, and Mr. Frank Fekel for generously providing some of the spectra used in this work. It is a pleasure to acknowledge KPNO for the use of the PDS microdensitometer, Grant measuring engine, KPNO radial velocity reduction program, and the spectrophotometric reduction programs, SPECT1 and SPECT2. I also thank Dr. Robert Kurucz for making WIDTH5 available. This work was submitted to the University of Texas in partial fulfillment of the requirements of the degree of Doctor of Philosophy.

APPENDIX A

In this appendix we clarify the meaning of the various subclassifications of the metallic-line and related stars.

Classical Am stars are stars which are classified Am according to the MK classification criteria defined by Roman, Morgan, and Eggen (1948). This usually means that the K-line type and the metal-line type differ by five or more subclasses. The hydrogen line types which are intermediate between the K-line types and metal-line types for these stars range from A4 through F1, and are consistent with the derived temperatures.

The classical Am (or Fm) stars are therefore metallic-line stars with pronounced line-strength anomalies. One should note, however, that misclassification may occur, as in the case of 15 Vul which Slettebak (1949) called Am by the Roman, Morgan, and Eggen criteria (hence we would call it classical Am), but which has been reclassi-

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fied A4 III (marginal Am?) by Cowley *et al.* (1969). The abundance analyses referenced in this paper support the latter classification. In addition, there are Am stars with pronounced abundance anomalies determined from curve-of-growth analyses which are not classified as classical Am stars, namely the early Am stars.

Early or hot Am stars are stars earlier than A4 which Conti (1965) pointed out have pronounced Am anomalies as evidenced by the Sc II λ4246/Sr II λ4215 line ratio. So far as is known, these stars are phenomenologically the same as the classical Am stars, but are not classified as classical Am because, at the surface temperature of the early A stars, the H lines are at their broad maximum, the K line is on the flat portion of the curve of growth, and the metal line strengths are weakening due to increased ionization, making the MK criteria insensitive to abundance anomalies.

Marginal or mild Am stars are Am stars in which the difference between the K-line type and the metal-line type is less than the five subclasses necessary for classification as a classical Am star.

There is a selection effect in the stars classified as marginal Am (Am:) by Cowley *et al.* (1969) in that the marginal Am stars are systematically hotter than the classical Am stars according to the $b - y$ or β temperature indicators of the $uvby\beta$ photometric system. There is therefore probably a large overlap in the hot Am and the marginal Am classifications. A photometric analysis of the marginal Am stars is presently in progress, and a complete discussion of this classification will be treated in a future publication.

Delta Delphini stars are stars with spectra similar to δ Del; that is, stars with subgiant and giant luminosity types and metal-line spectra similar to the Am stars. The δ Delphini classification is a spectroscopic classification only. We have shown in this paper that physically many of the δ Delphini stars are probably evolved Am stars.

F IVp–F IIp stars are early F subgiant and giant stars which are classified as peculiar by Morgan and Abt (1972) in their definition of the MKA system because the K-line type is earlier than the metal-line type. Malaroda (1973, 1975) uses the MKA criteria to classify stars as δ Delphini, and Anne Cowley (private communication) agrees that for classification purposes these MKA F IVp–F IIp stars are δ Delphini stars. Morgan and Abt call δ Del itself F0 IVp. Care should be taken not to confuse the MKA Fp stars with the very probably physically unrelated magnetic peculiar stars such as γ Eql or 49 Cam which are classified F0p (Cowley *et al.* 1969).

Delta Scuti stars are Population I short-period pulsating A and F stars within three magnitudes of the main sequence. The δ Scuti classification implies pulsational variability; it does not imply anything spectroscopic about a star. See Baglin *et al.* (1973) for a complete discussion.

APPENDIX B

EQUIVALENT WIDTH DATA FOR THE ABUNDANCE ANALYSES PRESENTED IN THIS STUDY

Table 12 is a listing of the stars and plate material used for the differential fine abundance analyses presented in this paper. The plates were traced using the KPNO PDS microdensitometer and converted to intensity using the KPNO spectrophotometric reduction programs SPECT1 and SPECT2 on the University of Texas CDC 6600 computer. Photographic density-to-intensity calibrations were used at 4100 and 4630 Å. All plates were IIa-O emulsion with projected slit widths of 20 μm and widening of 0.4–0.8 mm. Equivalent widths were measured treating all lines as triangles. The equivalent width data derived are presented in Table 13 along with the excitation potentials and oscillator strengths used which are from the lists of Corliss and Warner (1964), Corliss and

TABLE 12

PLATE MATERIAL USED FOR THE ABUNDANCE ANALYSES PRESENTED IN THIS STUDY

Star Name	HR	Plate Number	Dispersion (A mm^{-1})	Observatory	Telescope (m)	Observer
44 Tau.....	1287	EC6245	10	Lick	3.1	Kuhi
14 Aur.....	1706	Ce20609a	10	Mt. Wilson	2.5	Petersen
		B8925	8.6	McDonald	2.1	Kurtz
6 Mon.....	2255	B8507	8.6	McDonald	2.1	Smith
		B8924	8.6	McDonald	2.1	Kurtz
	2557	B8503	8.6	McDonald	2.1	Smith
ρ Pup......	3185	B8774	8.6	McDonald	2.1	Fekel
	3265	EC6249	10	Lick	3.1	Kuhi
20 CVn....	5017	D2011	8.9	KPNO	2.1	Smith
		B8929	8.6	McDonald	2.1	Kurtz
		B8930	8.6	McDonald	2.1	Kurtz
δ Del......	7928	D2843a	8.9	KPNO	2.1	Breger
		N597	8.0	McDonald	2.7	Kurtz
28 And....	114	N621	8.0	McDonald	2.7	Kurtz
γ Vir......	4825	D2847	8.9	KPNO	2.1	Breger
	8120	N613	8.0	McDonald	2.7	Kurtz
	8272	N610	8.0	McDonald	2.7	Kurtz

TABLE 13

Measured Equivalent Widths for the Program Stars (mÅ)

	λ(Å)	χ(eV)	log gf	HR114	HR4825	HR8120	HR8272
C I							
	4771.72	7.46	-1.70	59	32	51	119
	4775.85	7.46	-2.20	-	17	18	25
	4932.00	7.65	-1.92	62	-	37	22
Al I							
	3944.01	0.00	-0.62	195	143	131	202
	3961.52	0.01	-0.32	193	160	115	192
Si II							
	4128.05	9.79	0.22	144	35	127	-
	4130.88	9.80	0.77	57	42	106	108
S I							
	4694.13	6.50	-1.39	10.6	19	8.8	23
	4695.45	6.50	-1.54	-	-	13.4	30
	4696.25	6.50	-1.76	12.4	10.5	-	19
Ca I							
	4226.72	0.00	-0.55	295	-	161	316
	4283.01	1.88	-0.39	147	69	37	114
	4302.53	1.89	0.30	172	162	95	-
	4318.65	1.89	-0.15	-	-	-	60
	4425.43	1.87	-0.33	103	74	34	84
	4435.69	1.88	-0.69	65	53	31	79
	4455.89	1.88	-0.72	95	82	33	83
	4578.56	2.51	-0.82	26	48	21	23
	4585.87	2.52	-0.31	67	62	32	54
Sc II							
	4246.83	0.31	0.09	232	-	-	255
	4294.77	0.60	-1.27	39	25	38	38
	4305.70	0.59	-1.33	164	-	-	-
	4314.08	0.62	-0.10	191	117	231	207
	4320.76	0.60	-0.22	232	138	239	231
	4325.01	0.59	-0.37	147	97	134	-
	4374.45	0.62	-0.45	-	100	-	171
	4400.36	0.60	-0.80	156	82	142	135
	4415.56	0.59	-0.94	-	-	-	-
	4431.37	0.60	-2.02	25	-	21	17
Ti II							
	3913.46	1.12	-0.24	271	179	192	238
	4012.37	0.57	-1.58	178	100	178	186
	4028.33	1.89	-0.65	123	70	111	140
	4056.21	0.61	-2.46	-	24	30	50
	4163.63	2.58	0.45	-	98	-	181
	4294.10	1.08	-0.90	196	131	188	196
	4300.05	1.18	-0.46	269	-	209	253
	4301.93	1.16	-1.11	136	89	156	-
	4312.86	1.18	-1.06	159	111	149	192
	4367.66	2.69	-0.39	121	-	114	131
	4386.86	2.60	-0.46	77	48	-	78
	4390.98	1.23	-2.03	82	-	-	76
	4394.06	1.22	-1.47	100	47	98	116
	4395.03	1.08	-0.50	235	179	198	241
	4395.85	1.24	-1.53	67	45	78	85
	4399.76	1.24	-1.06	165	82	140	164
	4411.08	3.09	-0.07	57	31	85	74
	4411.94	1.22	-2.11	28	19	46	-
	4417.72	1.16	-1.18	181	92	154	179
	4418.34	1.24	-1.67	106	61	82	116
	4421.95	2.06	-1.14	-	19	60	77
	4443.80	1.08	-0.74	111	118	191	87
	4450.49	1.08	-1.41	92	111	129	170
	4464.46	1.17	-1.66	102	68	118	169
	4468.49	1.73	-0.65	218	105	175	240
	4488.32	3.12	0.01	76	56	92	99
	4493.53	1.08	-1.92	24	12.6	-	-
	4501.27	1.12	-0.79	232	152	201	240
	4529.46	1.57	-1.52	-	78	108	99
	4533.97	1.24	-0.64	-	207	261	277
	4544.01	1.24	-2.08	26	31	47	-
	4545.14	1.13	-1.61	46	22	64	67
	4563.76	1.22	-0.86	-	107	207	234
	4568.31	1.22	-1.93	29	27	-	-
	4571.97	1.57	-0.34	260	162	212	249
	4589.96	1.24	-1.61	129	113	129	128
	4779.99	2.04	-1.12	-	20	114	102
	4805.11	2.05	-0.74	-	-	168	153
V II							
	4002.94	1.43	-1.28	38	11.9	-	-
	4005.71	1.82	-0.22	-	-	-	-
	4008.17	1.79	-1.61	17	8.7	17	22
	4023.39	1.80	-0.35	61	37	80	62
	4036.78	1.48	-1.42	12.7	17	32	22
	4039.57	1.82	-1.60	9.8	22	14	-
	4183.43	2.05	-0.77	16	34	31	55
Cr I							
	3919.16	1.03	0.14	94	51	45	-
	4254.35	0.00	-0.27	149	-	108	190
	4274.80	0.00	-0.39	127	118	95	149
	4371.28	1.00	-0.90	33	50	-	-
	4511.90	3.07	0.37	20	9.1	-	25
	4591.39	0.96	-1.18	15	-	10.6	-
	4616.13	0.98	-0.95	57	24	48	-
	4646.17	1.03	-0.49	73	64	23	-
	4651.28	0.98	-0.97	33	22	9.9	17
	4652.16	1.00	-0.78	34	44	-	28
	4664.20	3.11	0.37	-	11.5	-	-
	4718.45	3.18	0.82	35	8.1	9.9	36

TABLE 13—*Continued*

	λ(Å)	χ(eV)	log gf	HR114	HR4825	HR8120	HR8272
Cr II							
	4209.35	3.83	-1.75	-	18	23	-
	4252.16	3.86	-1.85	31	17	57	54
	4261.92	3.86	-1.21	43	47	106	109
	4269.30	3.85	-2.06	36	-	-	-
	4275.58	3.86	-1.33	34	25	80	94
	4284.21	3.86	-1.85	38	21	57	59
	4555.02	4.07	-1.44	58	35	70	85
	4558.66	4.07	-0.45	156	90	196	182
	4588.22	4.07	-0.65	144	80	-	157
	4592.09	4.07	-1.37	74	80	91	99
	4616.64	4.07	-1.51	57	24	48	81
	4618.82	4.07	-0.98	144	96	108	133
	4634.11	4.07	-1.19	111	-	105	112
	4848.24	3.85	-1.13	74	59	-	115
	4876.41	3.86	-1.94	76	42	-	-
Mn I							
	4030.77	0.00	-0.48	-	-	138	240
	4033.07	0.00	-0.64	182	206	129	175
	4034.49	0.00	-0.88	125	90	61	119
	4035.73	2.11	0.37	108	106	99	121
	4041.36	2.11	0.93	65	108	-	113
	4048.76	2.13	0.25	69	95	-	133
	4055.54	2.13	0.47	31	50	25	-
	4082.94	2.17	0.25	-	17	-	65
	4083.62	2.13	0.24	25	83	28	99
	4502.22	2.91	0.18	18	22	-	19
	4754.04	2.27	0.13	34	79	-	-
	4783.42	2.29	0.11	-	56	-	82
Fe I							
	3815.84	1.48	0.60	279	302	-	-
	3865.82	1.01	-0.56	225	129	161	-
	3871.80	2.95	-0.15	95	70	41	-
	3872.50	0.99	-0.54	-	-	199	-
	3895.65	0.11	-1.47	-	147	183	-
	3902.94	1.56	0.12	273	157	-	244
	3920.26	0.12	-1.49	177	124	117	190
	3922.91	0.05	-1.41	194	112	125	181
	3927.92	0.11	-1.29	240	152	160	198
	3955.35	3.28	-0.41	-	50	37	-
	3983.96	2.73	0.06	99	102	69	-
	3998.05	2.69	-0.04	123	96	43	-
	4005.24	1.56	-0.07	-	251	-	-
	4007.27	2.76	-0.45	37	47	24	-
	4017.15	3.05	-0.17	90	94	-	79
	4021.87	2.76	0.12	114	69	-	85
	4029.64	3.26	-0.42	39	44	34	48
	4040.65	3.30	-0.30	41	49	28	-
	4043.90	2.73	-0.56	84	70	29	94
	4044.61	2.83	-0.17	51	68	19	-
	4045.81	1.48	0.68	-	377	249	333
Fe I							
	4047.32	2.28	-1.84	7.8	-	-	13.0
	4049.33	2.59	-1.35	21	22	-	-
	4059.72	3.54	-0.52	7.1	11.9	-	39
	4062.44	2.84	0.05	-	56	44	-
	4063.54	1.56	0.43	27	245	175	313
	4065.39	3.43	-0.70	-	18	-	-
	4067.98	3.21	0.29	74	80	36	96
	4070.76	3.24	0.01	64	49	-	-
	4071.74	1.61	0.40	237	217	-	217
	4072.52	3.43	-0.43	-	28	26	-
	4073.76	3.14	-0.14	64	33	25	51
	4074.79	3.05	-0.14	43	47	-	69
	4076.73	3.21	0.24	149	170	-	150
	4079.84	2.86	-0.52	40	-	11.0	-
	4084.49	3.33	0.13	49	-	-	81
	4091.56	2.83	-1.28	-	-	-	-
	4107.49	2.83	0.06	70	34	23	60
	4112.97	4.18	-0.02	37	52	-	-
	4114.44	2.83	-0.47	37	-	21	-
	4120.21	2.99	-0.43	26	31	-	24
	4123.74	2.61	-1.13	18	-	-	-
	4126.19	3.33	-0.35	29	64	-	42
	4132.06	1.61	-0.16	166	172	140	186
	4132.90	2.84	-0.02	63	-	-	80
	4133.86	3.37	-0.48	42	-	21	35
	4134.68	2.83	0.18	105	98	65	97
	4136.51	3.37	-0.82	8.8	12.6	8.0	-
	4137.00	3.14	0.12	87	70	-	68
	4139.93	0.99	-2.86	14.7	12.6	-	19
	4140.44	3.42	-1.11	-	14.7	8.5	-
	4141.86	3.02	-1.04	18	-	-	27
	4147.67	1.48	-1.47	89	100	22	25
	4153.90	3.40	0.33	127	151	-	117
	4156.80	2.83	0.13	108	172	-	-
	4157.78	3.42	0.17	76	69	-	72
	4174.92	0.91	-2.34	26	70	11.0	20
	4175.64	2.84	0.10	-	61	33	-
	4176.57	3.37	0.04	45	79	37	64
	4181.75	2.83	0.46	184	180	-	181
	4182.38	3.02	-0.37	18	73	-	-
	4184.89	2.83	-0.05	-	66	45	-
	4187.04	2.45	0.17	119	128	70	139
	4187.80	2.42	0.13	142	147	113	153
	4191.43	2.47	0.06	182	147	-	145
	4202.03	1.48	-0.25	218	175	158	228
	4203.98	2.84	-0.21	101	89	51	75
	4207.13	2.83	-0.69	44	59	-	-
	4210.35	2.48	-0.19	106	-	71	-
	4213.65	2.84	-0.55	33	31	17	51
	4216.29	0.00	-2.98	64	48	-	47
	4217.55	3.43	0.12	76	78	47	94
	4219.36	3.57	0.79	125	101	63	120
	4222.21	2.45	-0.35	85	65	65	112
	4225.46	3.42	0.13	100	79	-	-

TABLE 13—*Continued*

	λ(Å)	χ(eV)	log gf	HR114	HR4825	HR8120	HR8272
Fe I							
	4227.43	3.33	0.90	164	-	140	206
	4228.72	3.37	-1.65	-	-	-	-
	4235.94	2.42	0.31	192	-	129	181
	4238.81	3.40	0.47	-	55	80	114
	4240.37	3.55	-0.59	26	-	18	-
	4245.35	2.86	-0.44	54	47	34	89
	4246.09	3.64	-0.42	26	22	17	-
	4247.43	3.37	0.45	90	82	-	-
	4248.22	3.07	-0.53	23	29	12.3	39
	4250.12	2.47	0.25	-	102	89	160
	4250.79	1.56	-0.28	186	125	114	195
	4260.47	2.40	0.63	255	247	-	257
	4264.21	3.37	-0.78	-	20	13.4	26
	4266.96	2.73	-0.87	-	25	9.6	39
	4267.98	3.11	-0.34	42	33	18	32
	4268.74	3.30	-0.63	16	40	11.9	-
	4271.15	2.45	0.25	132	-	98	-
	4271.76	1.48	0.20	207	219	186	242
	4276.68	3.88	-0.75	-	12.7	-	-
	4282.41	2.18	-0.16	-	-	98	124
	4285.44	3.24	-0.42	34	42	-	42
	4291.46	1.56	-1.99	21	22	78	-
	4298.04	3.05	-0.56	24	43	-	32
	4325.76	1.61	0.36	147	214	178	195
	4327.92	3.30	-0.90	-	-	-	-
	4352.74	2.21	-0.56	77	42	-	-
	4375.93	0.00	-2.59	91	-	49	92
	4376.78	3.02	-1.27	11.9	8.7	9.3	11.7
	4382.78	3.57	-0.16	-	-	14.7	-
	4383.56	1.48	0.51	-	299	-	-
	4387.87	3.07	-0.62	22	50	-	-
	4388.41	3.60	0.02	68	74	-	-
	4392.58	3.88	-0.96	-	9.2	-	-
	4404.75	1.56	0.25	-	199	156	223
	4408.41	2.20	-0.95	58	91	38	70
	4415.12	1.61	-0.13	-	-	-	-
	4422.57	2.84	-0.22	-	56	-	97
	4427.31	0.05	-2.51	120	-	-	111
	4430.61	2.22	-1.02	56	83	-	90
	4432.57	3.57	-0.82	-	21	8.8	-
	4433.22	3.65	-0.14	55	-	-	36
	4438.35	3.69	-0.99	17	8.4	-	-
	4442.34	2.20	-0.50	138	-	65	-
	4443.19	2.86	-0.22	111	-	-	87
	4447.72	2.22	-0.58	90	66	67	88
	4466.58	2.83	0.18	132	-	78	103
	4469.38	3.65	0.19	115	78	88	-
	4476.02	2.84	0.14	127	102	77	137
	4479.61	3.69	-0.70	-	34	17	-
	4480.14	3.05	-1.01	-	-	14.8	-
	4484.23	3.60	0.08	53	59	37	46
	4485.67	3.68	-0.40	30	28	-	43
	4490.08	3.02	-0.74	28	32	-	-
Fe I							
	4494.57	2.20	-0.35	131	89	-	106
	4495.97	3.65	-0.99	-	18	-	12.7
	4517.53	3.07	-1.11	-	25	9.9	-
	4525.14	3.61	0.03	-	77	-	-
	4531.63	3.21	-1.20	11.9	26	-	-
	4547.85	3.55	-0.10	-	26	-	53
	4587.13	3.57	-0.91	24	26	11.2	21
	4602.00	1.61	-2.50	13.4	28	7.4	-
	4602.94	1.48	-1.46	-	-	-	-
	4607.67	3.26	-0.66	22	-	12.0	-
	4611.28	3.65	-0.13	-	60	-	69
	4625.05	3.24	-0.63	32	42	18	42
	4630.11	2.28	-1.83	-	-	-	-
	4632.92	1.61	-2.31	-	25	-	12.0
	4635.84	2.84	-1.46	-	9.8	-	-
	4637.51	3.28	-0.60	49	-	-	23
	4638.01	3.60	-0.35	64	42	-	51
	4643.46	3.65	-0.59	32	-	19	30
	4647.43	2.69	-0.47	60	-	24	32
	4668.14	3.26	-0.30	57	-	-	-
	4673.17	3.65	-0.53	-	38	-	16
	4678.86	3.60	0.05	58	-	-	65
	4690.17	3.69	-0.79	-	10.9	-	18
	4691.42	2.99	-0.54	48	42	21	-
	4705.46	3.55	-1.27	-	12.6	-	-
	4707.28	3.24	-0.23	58	71	-	-
	4710.28	3.02	-0.74	35	35	-	32
	4733.60	1.48	-2.38	-	37	-	-
	4735.85	4.08	-0.37	-	21	-	-
	4736.78	3.21	-0.02	-	95	-	81
	4745.81	3.65	-0.55	-	14.7	-	-
	4772.82	3.02	-1.05	25	23	-	-
Fe II							
	4122.63	2.58	-2.73	89	73	112	104
	4128.73	2.58	-2.76	57	48	72	68
	4178.85	2.58	-2.00	145	137	178	210
	4233.16	2.58	-1.43	-	201	-	-
	4273.31	2.70	-2.27	-	70	106	125
	4296.56	2.70	-2.36	132	82	133	139
	4303.16	2.70	-2.00	177	109	149	176
	4351.76	2.70	-1.76	-	-	218	-
	4385.38	2.78	-2.02	155	106	190	161
	4416.81	2.78	-2.09	115	-	135	156
	4472.92	2.84	-2.80	66	35	75	87
	4489.18	2.83	-2.23	132	93	156	124
	4491.40	2.85	-2.09	-	87	156	140
	4508.28	2.85	-1.76	-	82	178	191
	4515.33	2.84	-1.91	178	96	168	191
	4520.24	2.81	-1.87	166	-	149	174
	4522.63	2.84	-1.51	211	109	207	233

TABLE 13—*Continued*

	λ(Å)	χ(eV)	log gf	HR114	HR4825	HR8120	HR8272
Fe II							
	4541.52	2.85	-2.29	-	51	-	132
	4555.89	2.83	-1.79	246	-	215	238
	4576.33	2.84	-2.22	-	50	127	125
	4582.83	2.84	-2.44	97	72	102	-
	4583.82	2.81	-1.25	242	168	245	244
	4620.51	2.83	-2.63	78	52	93	56
	4629.33	2.81	-1.78	166	70	158	187
	4635.35	5.95	-1.43	-	-	-	38
	4656.97	2.89	-2.53	135	66	-	149
	4666.75	2.83	-2.64	83	70	-	102
	4670.17	2.58	-2.87	-	41	110	89
	4731.44	2.89	-2.29	142	79	-	92
	4923.92	2.88	-0.93	253	-	-	-
Co I							
	4020.90	0.43	-1.58	7.1	11.1	-	7.1
	4058.60	2.00	-0.67	26	54	13.8	51
	4121.32	0.92	-0.03	39	32	24	33
Ni I							
	3858.30	0.42	-0.62	166	132	87	-
	4401.55	3.18	0.83	-	98	39	87
	4606.99	3.47	0.77	-	55	30	39
	4606.23	3.58	0.30	-	16	23	9.9
	4648.65	3.47	0.78	66	41	13.1	42
	4686.22	3.58	-0.39	21	12.2	-	-
	4714.42	3.37	0.84	88	45	47	76
	4715.78	3.53	0.76	34	-	13.9	20
Ni II							
	4015.50	4.03	-1.25	63	57	34	54
	4067.05	4.03	-0.59	132	157	125	176
	4244.80	4.03	-2.03	-	34	-	29
	4362.10	4.03	-1.43	-	14.7	37	-
Zn I							
	4722.22	4.01	0.69	29	35	5.4	31
	4810.53	4.06	0.86	14.9	27	19	50
Sr II							
	4077.71	0.00	-0.78	283	276	216	309
	4215.52	0.00	-0.99	248	241	214	268
Y II							
	3950.35	0.10	-0.71	111	-	-	80
	3982.59	0.13	-0.79	65	45	82	87
	4177.54	0.41	-0.24	186	196	196	210
	4309.62	0.18	-0.98	106	163	96	-
	4358.73	0.10	-1.61	24	54	37	23
	4374.94	0.41	-0.14	-	-	-	171
	4398.02	0.13	-1.25	49	-	-	53
Zr II							
	4149.22	0.80	-0.13	118	127	98	133
	4150.97	0.80	-1.02	-	10.1	18	38
	4156.24	0.71	-0.85	79	50	49	79
	4208.99	0.71	-0.54	41	-	51	64
	4211.88	0.52	-1.21	12.7	10.5	43	27
	4317.32	0.71	-1.48	24	6.9	8.9	-
Ba II							
	4554.03	0.00	0.17	220	-	135	204
	4934.10	0.00	-0.14	173	-	183	124
La II							
	3988.51	0.40	-0.26	11.5	-	16	11
	4086.72	0.00	-0.60	16	26	24	-
	4123.23	0.32	-0.40	22	25	24	20
	4263.59	1.95	0.03	(4.8)	-	10.2	17
	4322.51	0.17	-1.62	-	-	-	-
	4333.76	0.17	-0.60	52	14.1	-	-
	4662.51	0.00	-2.04	(4.5)	-	14.1	-
	4748.73	0.92	-1.20	-	5.4	9.7	13.1
Ce II							
	3882.45	0.32	-0.06	-	56	-	133
	4120.83	0.32	-0.74	(4.2)	-	-	-
	4137.65	0.04	0.09	27	29	14.8	8.2
	4142.40	0.22	-0.14	31	45	13.8	-
	4193.09	0.74	-0.10	-	(4.0)	4.5	-
	4202.94	0.56	-0.34	7.4	-	5.7	10.5
	4418.76	0.38	0.03	25	13.6	17	-
	4486.91	0.29	-0.62	10.9	6.4	5.0	5.8
Nd II							
	4061.09	0.47	0.03	17.8	(5.0)	-	18
	4462.98	0.56	-0.84	22	25	-	110
Sm II							
	4424.34	0.48	-0.42	-	14.0	9.2	16
	4467.34	0.66	-0.39	7.4	6.7	-	-
Eu II							
	4129.73	0.00	-0.31	20	16.8	12.0	13
	4205.05	0.00	-0.08	61	46	-	-
Gd II							
	4251.73	0.38	-0.39	-	(4.7)	10.2	12.5

TABLE 13—*Continued*

	λ(Å)	HR1287	HR1706	HR2255	HR2557	HR3185	HR3265	HR5017	HR7928
C I									
	4771.72	-	31	106	64	-	122	143	76
	4775.85	-	23	49	29	37	34	44	41
	4932.00	-	79	-	-	24	-	-	30
Al I									
	3944.01	204	184	221	212	266	247	247	191
	3961.52	178	131	220	148	224	162	199	171
Si II									
	4128.05	135	120	162	196	279	-	204	89
	4130.88	75	95	164	98	259	206	230	107
S I									
	4694.13	-	21	49	45	65	18	37	43
	4695.45	-	16.6	26	29	23	10.1	37	14.9
	4696.25	-	15.3	17	35	11.0	5.2	18	20
Ca I									
	4226.72	363	289	319	338	396	369	364	268
	4283.01	148	97	128	-	167	126	158	93
	4302.53	195	166	162	210	240	-	195	123
	4318.65	151	-	-	116	-	120	-	-
	4425.43	146	78	120	99	162	85	158	79
	4435.69	139	68	151	91	210	-	173	95
	4455.89	132	51	120	-	168	122	146	79
	4578.56	57	25	52	-	65	39	81	40
	4585.87	124	37	98	87	118	65	146	43
Sc II									
	4246.83	197	222	249	-	280	249	274	155
	4294.77	84	45	74	62	95	44	128	15
	4305.70	-	-	-	220	-	-	-	-
	4314.08	212	196	280	254	325	278	303	163
	4320.76	-	219	281	290	333	261	316	141
	4325.01	180	112	192	197	233	-	232	94
	4374.45	178	-	201	302	205	-	219	91
	4400.36	155	106	196	153	177	179	237	81
	4415.56	153	-	154	-	169	-	188	70
	4431.37	26	14.8	41	62	50	10.1	79	8.6
Ti II									
	3913.46	266	238	278	319	362	325	314	217
	4012.37	221	188	278	212	290	298	307	170
	4028.33	146	149	172	185	179	156	196	89
	4056.21	62	52	66	-	-	30	142	12.8
	4163.63	188	145	199	-	257	176	232	111
	4294.10	231	198	234	203	299	196	244	175
	4300.05	264	225	285	250	372	298	311	181
Ti II									
	4301.93	192	190	240	255	276	236	253	121
	4312.86	210	147	210	197	256	159	234	120
	4367.66	184	115	184	194	260	162	202	98
	4386.86	113	70	129	111	168	111	171	60
	4390.98	146	74	153	131	216	146	198	70
	4394.06	144	96	136	123	175	99	178	57
	4395.03	266	219	260	274	326	240	302	186
	4395.85	124	54	130	100	143	196	175	43
	4399.76	193	140	204	217	252	64	232	117
	4411.08	107	57	94	73	143	-	149	41
	4411.94	82	29	56	48	101	26	110	13.4
	4417.72	192	150	180	167	250	175	216	118
	4418.34	131	49	99	-	153	99	158	46
	4421.95	100	53	84	-	138	53	142	20
	4443.80	227	187	216	-	292	-	248	173
	4450.49	183	140	212	169	-	222	249	113
	4464.46	168	106	161	160	266	166	212	80
	4468.49	227	179	240	-	299	222	245	163
	4488.32	139	63	116	105	180	88	166	50
	4493.53	62	22	46	61	81	22	84	93
	4501.27	228	176	260	190	296	234	269	164
	4529.46	165	55	149	119	196	103	195	53
	4533.97	290	252	310	297	352	298	329	-
	4544.01	65	26	72	107	82	31	96	23
	4545.14	84	34	93	96	-	53	127	37
	4563.76	239	156	233	217	260	205	261	155
	4568.31	-	18	37	47	-	10.1	83	-
	4571.97	260	196	298	260	325	302	319	198
	4589.96	142	95	161	-	192	92	187	77
	4779.99	-	75	88	120	-	-	154	74
	4805.11	-	102	162	-	220	-	180	112
V II									
	4002.94	72	141	54	134	-	155	29	
	4005.71	116	-	162	-	-	-	197	80
	4008.17	-	21	42	40	-	-	98	12.3
	4023.39	110	81	131	96	150	118	165	55
	4036.78	38	36	57	33	66	36	97	11.5
	4039.57	18	27	26	55	52	13.8	47	8.4
	4183.43	71	39	77	-	104	111	128	18
Cr I									
	3919.16	158	64	138	-	186	130	170	74
	4254.35	207	164	216	-	277	196	248	140
	4274.80	204	130	192	-	276	203	221	137
	4371.28	115	49	92	-	99	121	104	44
	4511.90	31	13.2	24	-	47	15	36	17
	4591.39	48	14.2	46	-	50	26	66	7.7
	4616.13	64	54	52	97	92	-	92	19
	4646.17	-	36	101	92	170	-	129	44
	4651.28	-	14.7	40	52	70	18	59	24
	4652.16	-	26	47	41	94	34	77	32
	4664.20	-	14.8	12.8	-	-	-	-	-
	4718.45	-	18	28	46	69	-	64	20

TABLE 13—*Continued*

	λ(Å)	HR1287	HR1706	HR2255	HR2557	HR3185	HR3265	HR5017	HR7928
Cr II									
	4209.35	-	14.9	23	-	-	44	-	-
	4252.16	63	43	69	-	165	85	140	36
	4261.92	126	95	149	124	211	142	193	73
	4269.30	68	33	108	92	134	110	157	35
	4275.58	123	60	116	103	176	99	161	56
	4284.21	99	51	81	98	153	99	143	34
	4555.02	109	56	88	125	146	85	141	74
	4558.66	194	143	210	-	240	204	239	119
	4588.22	156	124	176	149	205	137	199	67
	4592.09	114	78	112	-	141	141	157	19
	4616.64	101	35	99	101	136	78	133	51
	4618.82	156	78	144	176	220	126	192	93
	4634.11	134	77	122	144	185	92	161	83
	4848.24	-	-	110	-	159	-	138	77
	4876.41	-	-	167	-	165	-	173	-
Mn I									
	4030.77	-	-	-	-	-	-	299	218
	4033.07	230	177	219	262	290	289	270	177
	4034.49	176	133	173	140	231	187	204	124
	4035.73	171	145	178	137	237	170	228	94
	4041.36	158	113	155	141	232	162	203	104
	4048.76	134	118	179	137	227	205	227	115
	4055.54	98	75	96	91	168	83	130	51
	4082.94	87	13.1	73	60	96	53	97	-
	4083.62	147	48	120	109	177	114	176	51
	4502.22	36	8.9	33	39	63	16	38	89
	4754.04	-	27	87	-	171	75	102	51
	4783.42	-	43	101	73	-	107	107	60
Fe I									
	3815.84	-	-	-	313	-	303	-	-
	3865.82	-	-	254	-	-	240	-	-
	3871.80	122	-	212	-	188	214	208	-
	3872.50	-	-	-	-	-	-	-	-
	3895.65	202	-	268	-	293	245	232	175
	3902.94	232	221	340	296	-	331	256	208
	3920.26	190	165	225	188	228	231	217	162
	3922.91	224	167	263	228	283	278	265	189
	3927.92	220	177	275	225	264	312	245	216
	3955.35	108	37	105	52	132	73	153	54
	3983.96	148	86	167	-	228	179	222	103
	3998.05	158	88	163	138	264	187	208	99
	4005.24	116	261	-	-	-	-	275	210
	4007.27	83	45	123	-	124	-	125	34
	4017.15	122	87	128	182	159	146	171	-
	4021.87	148	95	155	143	239	196	215	121
	4029.64	101	93	115	-	137	142	140	77
	4040.65	98	51	126	112	205	-	174	-
	4043.90	127	62	123	-	196	117	170	74
	4044.61	108	59	96	-	151	99	147	58
	4045.81	431	314	420	436	537	428	462	360
Fe I									
	4047.32	-	10.1	22	31	42	7.6	29	15
	4049.33	-	21	49	-	82	47	73	23
	4059.72	48	26	58	27	110	47	86	29
	4062.44	113	92	167	86	185	162	184	89
	4063.54	275	253	339	368	405	368	286	267
	4065.39	55	24	80	66	-	34	79	21
	4067.98	136	97	124	-	186	123	173	85
	4070.76	110	73	118	-	150	114	151	62
	4071.74	272	210	263	244	262	267	276	192
	4072.52	67	28	59	72	85	-	111	19
	4073.76	101	59	125	-	129	-	129	65
	4074.79	115	48	113	71	148	110	147	61
	4076.73	-	152	188	214	-	240	257	139
	4079.84	84	28	67	90	-	-	105	55
	4084.49	120	49	96	-	126	66	123	55
	4091.56	29	-	19	15	29	6.1	29	-
	4107.49	97	38	114	80	141	85	108	70
	4112.97	-	35	74	77	115	43	107	31
	4114.44	72	29	72	37	76	49	96	36
	4120.21	80	23	67	80	103	62	103	35
	4123.74	96	32	106	89	121	72	147	54
	4126.19	102	34	95	-	141	70	119	38
	4132.06	256	160	263	275	314	319	294	188
	4132.90	117	77	101	-	188	148	149	80
	4133.86	84	59	120	-	163	107	142	54
	4134.68	166	126	162	-	279	162	209	113
	4136.51	34	-	37	52	-	-	56	19
	4137.00	112	59	109	79	197	-	156	73
	4139.93	-	10.5	23	22	70	20	57	-
	4140.44	33	12.0	35	23	65	22	59	14.6
	4141.86	43	13.5	61	-	-	-	86	19
	4147.67	128	62	114	129	169	122	151	71
	4153.90	164	110	133	-	249	-	217	99
	4156.80	169	97	143	-	224	-	220	124
	4157.78	130	80	94	93	186	117	154	82
	4174.92	95	147	95	78	162	62	112	44
	4175.64	139	80	116	75	205	141	159	91
	4176.57	130	61	108	107	192	116	151	74
	4181.75	-	158	198	193	328	249	254	165
	4182.38	85	43	86	33	162	90	127	49
	4184.89	111	73	105	71	187	114	143	93
	4187.04	178	149	176	-	281	267	219	138
	4187.80	230	141	221	181	314	249	251	147
	4191.43	206	140	229	-	-	258	262	141
	4202.03	240	217	279	250	379	285	310	192
	4203.98	157	74	127	91	224	137	201	89
	4207.13	78	39	72	66	174	114	149	41
	4210.35	163	100	168	-	225	170	185	112
	4213.65	64	44	76	51	146	82	110	54
	4216.29	110	29	118	48	205	-	157	80
	4217.55	110	59	139	41	192	130	148	80
	4219.36	164	98	143	107	234	161	196	99
	4222.21	143	104	161	153	249	201	179	104
	4225.46	113	129	156	160	-	214	225	103

TABLE 13—*Continued*

λ(Å)	HR1287	HR1706	HR2255	HR2557	HR3185	HR3265	HR5017	HR7928
Fe I								
4227.43	209	165	215	217	273	279	279	155
4228.72	-	21	-	19	25	-	34	-
4235.94	228	169	244	186	325	305	256	187
4238.81	159	100	156	109	257	-	201	101
4240.37	69	29	49	41	-	31	110	25
4245.35	127	49	103	-	200	114	162	61
4246.09	67	24	72	-	131	92	114	36
4247.43	171	96	151	101	184	154	189	111
4248.22	74	31	71	79	-	-	106	43
4250.12	179	126	183	-	268	-	209	124
4250.79	202	167	212	-	269	-	239	160
4260.47	256	214	266	-	367	279	268	196
4264.21	44	21	34	32	92	-	74	23
4266.96	50	30	51	59	115	42	73	23
4267.98	94	33	68	55	130	56	96	37
4268.74	71	26	58	-	-	-	99	36
4271.15	199	150	202	-	250	-	225	143
4271.76	268	202	285	-	354	-	277	208
4276.68	31	16	34	46	-	13.6	57	20
4282.41	165	117	198	145	253	214	222	130
4285.44	87	28	80	-	143	88	114	45
4291.46	53	17	43	67	103	21	70	-
4298.04	81	27	65	81	-	-	86	32
4325.76	292	206	315	280	359	-	308	228
4327.92	25	-	30	30	-	16	59	10.9
4352.74	137	47	112	72	164	67	147	73
4375.93	123	54	128	116	185	82	146	86
4376.78	22	23	23	31	53	11.6	38	5.6
4382.78	-	39	44	48	82	53	80	32
4383.56	282	220	292	288	357	-	283	247
4387.87	64	43	59	55	122	107	110	28
4388.41	103	40	92	82	159	68	146	52
4392.58	16	-	14.7	41	47	-	57	5.6
4404.75	255	189	262	257	335	-	280	218
4408.41	-	59	105	-	204	141	169	68
4415.12	225	-	230	-	335	-	261	201
4422.57	131	58	145	-	201	146	167	96
4427.31	160	89	150	-	217	156	196	107
4430.61	129	60	89	105	192	130	164	68
4432.57	19	17	16.8	-	47	-	52	13.0
4433.22	78	34	75	83	121	82	111	46
4438.35	17	11.1	25	33	52	10.1	54	9.5
4442.34	147	75	81	127	193	-	163	93
4443.19	112	89	135	-	199	-	164	115
4447.72	137	60	111	97	184	127	152	.98
4466.58	148	104	155	117	207	162	186	119
4469.38	-	84	141	-	232	145	202	88
4476.02	177	85	145	121	236	154	186	123
4479.61	37	18	49	48	-	-	83	27
4480.14	-	13.6	45	-	-	-	80	17
4484.23	-	33	87	-	131	114	115	63
4485.67	64	14.4	71	45	-	48	76	28
4490.08	69	28	54	-	-	62	82	33
4494.57	174	93	177	165	243	175	183	118
4495.97	-	10.0	42	40	-	14.2	48	10.9
4517.53	43	16	39	56	72	22	57	14.9
4525.14	128	65	138	113	242	150	175	99
4531.63	29	-	20	-	-	-	34	-
4547.85	69	23	61	97	107	53	97	42
4587.13	45	11.4	25	27	42	-	52	10.9
4602.00	-	14.1	33	-	-	13.8	46	17
4602.94	122	43	89	51	153	75	130	63
4607.67	-	16.2	71	50	84	75	92	45
4611.28	118	34	85	73	160	72	143	69
4625.05	87	22	77	66	116	59	102	43
4630.11	-	18	38	15	54	18	56	35
4632.92	64	21	53	-	-	26	88	32
4635.84	35	24	30	-	55	26	27	38
4637.51	71	37	46	71	115	-	94	-
4638.01	68	29	72	60	118	-	94	62
4643.46	44	40	57	-	-	34	74	36
4647.43	-	-	91	85	180	78	136	64
4668.14	-	-	84	105	167	-	106	63
4673.17	-	29	72	83	94	36	85	-
4678.86	-	40	78	116	-	85	113	80
4690.17	-	21	20	43	46	-	47	19
4691.42	-	-	76	75	167	-	137	54
4705.46	-	-	24	35	-	-	21	15
4707.28	-	54	83	80	184	-	115	65
4710.28	-	31	60	51	100	-	84	37
4733.60	-	-	42	71	-	-	68	-
4735.85	-	11.3	35	-	80	-	53	28
4736.78	-	-	108	77	-	-	140	80
4745.81	-	12.1	60	50	-	-	58	62
4772.82	-	-	30	50	-	-	61	45
Fe II								
4122.63	163	99	168	160	197	141	208	95
4128.73	135	57	89	111	123	89	149	-
4178.85	185	160	216	225	273	263	256	152
4233.16	266	260	259	358	372	-	304	225
4273.31	123	96	169	140	209	164	183	82
4296.56	184	128	220	189	266	222	243	140
4303.16	186	147	189	202	268	236	217	145
4351.76	-	-	-	298	-	309	-	-
4385.38	188	134	214	-	294	170	240	141
4416.81	179	130	182	-	231	168	204	127
4472.92	157	47	133	-	216	147	172	60
4489.18	172	102	170	145	251	146	218	106
4491.40	170	127	166	142	233	149	190	119
4508.28	190	117	215	167	278	190	233	160
4515.33	192	115	197	151	264	179	220	150
4520.24	182	128	182	176	248	170	215	143
4522.63	228	166	254	210	305	303	301	196

TABLE 13—*Continued*

	λ(Å)	HR1287	HR1706	HR2255	HR2557	HR3185	HR3265	HR5017	HR7928
Fe II									
	4541.52	149	88	167	148	190	148	177	111
	4555.89	-	154	250	215	299	281	281	180
	4576.33	134	85	147	-	181	137	174	97
	4582.83	125	76	124	80	171	122	157	81
	4583.82	240	187	272	-	316	267	277	204
	4620.51	108	56	105	92	163	72	144	88
	4629.33	182	116	216	202	255	201	213	187
	4635.35	-	-	74	-	-	26	-	-
	4656.97	-	84	131	-	243	92	192	76
	4666.75	-	70	132	162	243	141	186	89
	4670.17	-	70	166	141	202	122	199	-
	4731.44	-	64	143	-	225	-	174	99
	4923.92	-	-	-	-	330	-	-	243
Co I									
	4020.90	21	10.7	23	19	50	34	53	18
	4058.60	128	52	98	89	146	53	150	40
	4121.32	100	37	105	60	127	96	106	45
Ni I									
	3858.30	173	-	272	-	303	218	-	-
	4401.55	163	79	165	-	255	187	199	117
	4606.99	60	28	61	54	120	53	105	46
	4606.23	-	-	49	69	40	36	56	16
	4648.65	-	37	100	92	176	85	124	70
	4686.22	-	14.6	46	-	77	26	59	-
	4714.42	-	59	117	54	208	150	167	103
	4715.78	-	25	56	28	-	59	83	35
Ni II									
	4015.50	94	51	122	80	143	145	182	70
	4067.05	174	159	238	-	-	285	232	159
	4244.80	8.9	8.0	31	35	55	82	51	10.3
	4362.10	32	18.2	63	62	74	41	84	26
Zn I									
	4722.22	-	12.1	83	13	108	68	85	57
	4810.53	-	47	104	35	153	68	85	78
Sr II									
	4077.71	365	320	437	386	531	618	401	382
	4215.52	328	268	362	406	394	445	333	296
Y II									
	3950.35	94	107	179	107	154	-	152	125
	3982.59	86	75	185	-	168	162	153	111
	4177.54	228	224	314	303	364	394	310	249
	4309.62	143	120	221	191	327	287	213	73
	4358.73	110	37	141	50	169	222	146	158
	4374.94	200	-	245	-	288	-	247	201
	4398.02	-	-	156	-	188	-	139	105
Zr II									
	4149.22	184	157	237	176	275	274	238	166
	4150.97	86	33	100	52	76	103	84	42
	4156.24	142	103	201	-	232	-	218	112
	4208.99	62	56	141	-	-	196	133	90
	4211.88	67	47	135	47	120	114	128	65
	4317.32	23	10.5	68	40	47	24	41	19
Ba II									
	4554.03	215	168	273	169	310	302	264	230
	4934.10	-	196	-	-	256	-	-	232
La II									
	3988.51	36	22	138	69	91	101	141	56
	4086.72	40	26	94	-	82	107	106	58
	4123.23	62	26	108	-	115	92	131	54
	4263.59	-	20	35	28	37	39	48	11.9
	4322.51	7.4	10.2	35	34	23	18	31	6.8
	4333.76	38	25	91	38	95	56	109	50
	4662.51	-	6.3	40	43	-	22	50	8.5
	4748.73	-	-	33	-	24	13.8	33	-
Ce II									
	3882.45	-	-	194	-	-	162	-	-
	4120.83	6.2	9.4	31	38	24	44	37	6.0
	4137.65	30	38	96	52	135	99	115	49
	4142.40	68	57	119	97	177	146	169	55
	4193.09	9.7	11.5	53	21	30	33	44	10.2
	4202.94	11.7	15.6	72	42	92	78	93	27
	4418.76	-	13.3	48	37	59	-	59	22
	4486.91	23	8.7	28	9.4	32	34	50	13.0
Nd II									
	4061.09	38	26	64	-	99	72	89	43
	4462.98	7.7	15.3	23	45	45	67	32	21
Sm II									
	4424.34	38	21	45	28	75	34	68	16
	4467.34	12.6	18	44	30	42	56	34	20
Eu II									
	4129.73	40	21	136	23	180	109	148	79
	4205.05	96	73	210	196	275	276	233	142
Gd II									
	4251.73	20	17	55	43	67	36	56	20

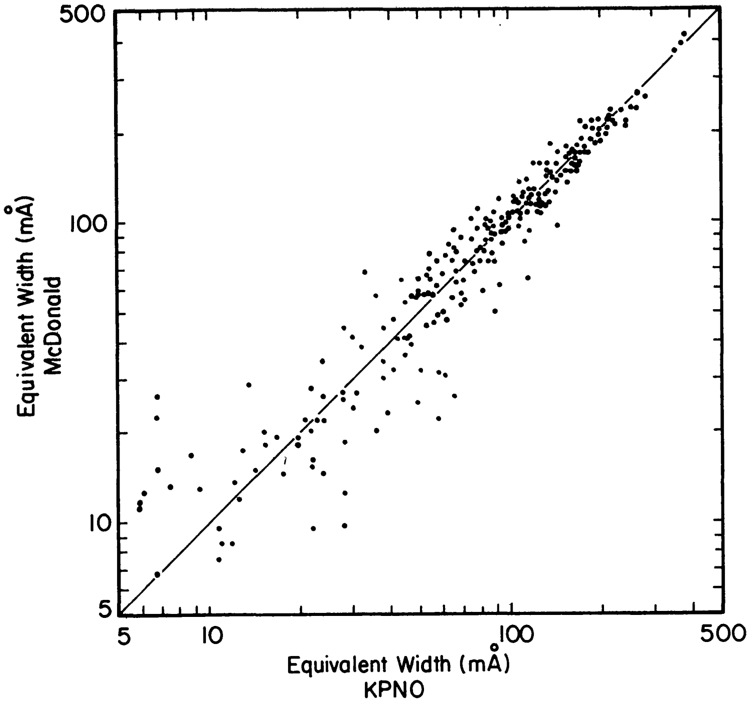

FIG. 10.—Comparison of the equivalent widths measured by the author for δ Del from a McDonald 2.7 m telescope 8.0 Å mm^{-1} plate and a KPNO 2.1 m telescope 8.9 Å mm^{-1} plate.

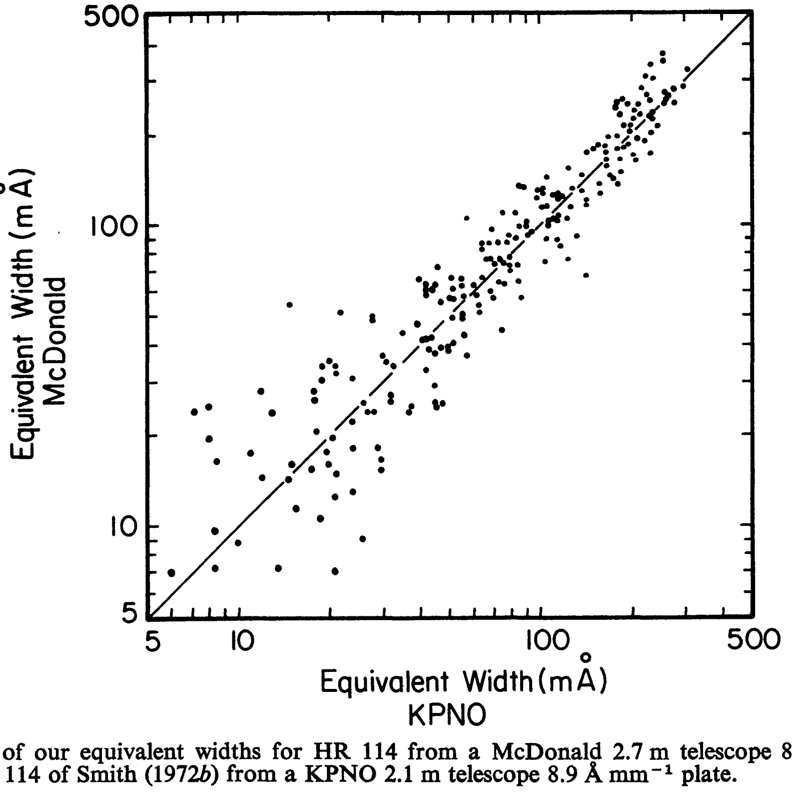

FIG. 11.—Comparison of our equivalent widths for HR 114 from a McDonald 2.7 m telescope 8.0 Å mm^{-1} plate with the equivalent widths for HR 114 of Smith (1972*b*) from a KPNO 2.1 m telescope 8.9 Å mm^{-1} plate.

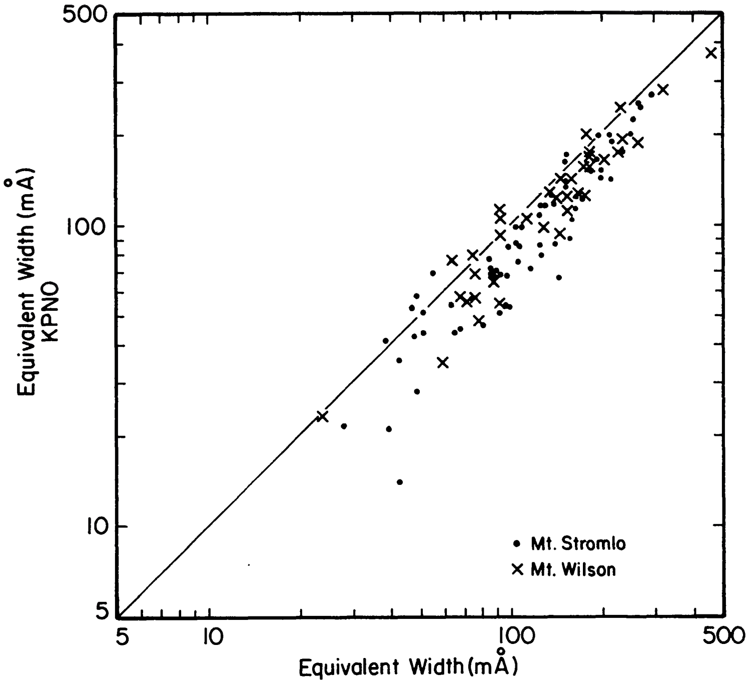

FIG. 12.—Comparison of our equivalent widths for δ Del with those of Bessell (1969) and Reimers (1969). Bessell and Reimers agree with each other, whereas our equivalent widths are smaller than theirs. Note, however, that our equivalent widths from two plates of δ Del are in good internal agreement, as shown in Fig. 10.

Bozman (1962), Lambert and Warner (1968*a*, *b*, *c*, *d*), and Warner (1967). The oscillator strengths used are not the most recent but rather were chosen to be the same as those used by Smith (1971, 1973*a*) for most of the line list in order to facilitate intercomparison of the δ Delphini star abundances and Smith's Am and Fm star abundances. Because all abundances were derived differentially, errors in oscillator strength values cancel out to first approximation. A critical discussion of more recent oscillator strengths useful in the analysis of A and F stars is given by Ishikawa (1973, 1975).

We have compared the equivalent-width data used in this analysis with other published equivalent-width data for the same stars and find on the average no systematic shift. The mean scatter of our equivalent widths compared with others is ±0.09 dex. In Figures 10, 11, and 12 we have plotted some representative examples comparing our data from different telescopes and with the data of other investigators. Figure 10 compares our equivalent widths for δ Del from a plate taken with the McDonald 2.7 m telescope at 8 Å mm^{-1} and a plate taken with the KPNO 2.1 m telescope at 8.9 Å mm^{-1}. Figure 11 compares our equivalent widths for HR 114 with those of Smith (1971). Both of these figures are typical of most of the equivalent-width comparisons made both internally and with the published equivalent widths of other investigators. Figure 12 represents a worst case. In it, equivalent widths of δ Del from a McDonald 2.1 m telescope 8.6 Å mm^{-1} plate are compared with those measured by Bessell (1969) at 6.8 Å mm^{-1} at Mount Stromlo and Reimers (1969) at 10 Å mm^{-1} at Mount Wilson. There is a systematic shift of our equivalent widths compared with theirs of about 20% or 0.08 dex. No explanation of this shift is offered. Bessell and Reimers's data are in good agreement but the author's data shown in Figure 12 are also compared with another plate of δ Del in Figure 10, with good agreement there, also.

We have used a heterogeneous group of plates from different telescopes and observatories, but find that the equivalent-width scales derived from plates of comparable dispersion are usually in good agreement with those of other investigators, regardless of the equipment used to obtain the plates. The rms scatter in the compared equivalent widths is ±0.09 dex. In some cases our equivalent widths differ from those in the literature by as much as 20%. Although such a shift in the equivalent-width scale is exceptional in this analysis, it must be kept in mind in any interpretation of the data presented herein that such a shift may be present. Special care should be taken especially in the case of stars for which only one plate was measured.

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