# NON-MAGNETIC INTERMEDIATE-TEMPERATURE STARS: A REVIEW

M. M. Dworetsky
Department of Physics and Astronomy
University College London
Gower Street, London WC1E 6BT
England

ABSTRACT. The literature concerning spectroscopic studies, abundances, photometry, and systematics of intermediate-temperature (9500 K < $T_{eff}$ < 16000 K) normal, Hg-Mn, and related stars is reviewed. The review is restricted mainly to papers published since the last international meeting on chemically peculiar stars at Liège in June 1981, and is intended to be complete to 31 December 1984.

## 1. INTRODUCTION

It would be logical to start by defining carefully what I mean by the phrase "non-magnetic intermediate-temperature" stars. By non-magnetic I mean those upper main-sequence peculiar and normal stars which, as a group, have observed magnetic fields which are not significantly different from zero. We should bear in mind that the existence of undetected very weak fields is by no means excluded as a possibility. By intermediate-temperature I mean, somewhat loosely, those stars with 9500 K < $T_{eff}$ < 16000 K, i.e., A0 - B5 stars, but out of necessity I will allow myself the liberty of relaxing the lower limit slightly in order to include a few specific objects.

To produce a complete review, I found it necessary to make some incursions into areas which are being reviewed at this Colloquium by Dr. Leckrone (Space Observations). I intend to make no distinction in principle between observations from space and those from the ground (referred to as 'optical' or 'visible' in this review). The review will encompass normal stars, Hg-Mn stars, related objects, and metal-weak λ-Boötis stars. Previous reviews covering earlier work include those by Wolff and Wolff (1976) on Hg-Mn stars, and those by Bonsack and Wolff (1980) and Hack (1981) on the more general problems of the observed properties of chemically peculiar stars. Brief discussions of recent results concerning peculiar stars in open clusters, X-ray observations, and microturbulence are also given.

*C. R. Cowley et al (eds.), Upper Main Sequence Stars with Anomalous Abundances, 397–416.*

## 2. NORMAL STARS: ABUNDANCES

### 2.1. General Remarks

Observers of normal stars have been exceptionally busy during the past few years; some rather remarkable results have emerged which are upsetting preconceived ideas. From the point of view of the student of chemically peculiar stars, normal A and B stars serve as comparison objects. However, they are of increasing interest in themselves, partly because the spread of abundances being deduced is surprising large.

The normal star to which all abundance determinations are ultimately compared is the Sun. Grevesse (1984) gives a critical compilation of solar photospheric abundances, and a comparison with the recent critical review of C1 carbonaceous chondrite abundances by Anders and Ebihara (1982). Grevesse's compilation is probably the best summary now available, and I recommend its use.

However, those of us who are stellar spectroscopists prefer to use normal comparison stars which have effective temperatures closer to those of the chemically peculiar stars we are analyzing. We are also well aware that the average normal late B or A0 main-sequence star has a high rotational velocity ($< v \sin i > = 150$ km $s^{-1}$) which renders it useless for detailed spectroscopic analysis. Those stars which have been studied during the review period all have small values of v sin i.

One very important point is that the analyses I summarize below were nearly all made using the new fully-line-blanketed LTE models of Kurucz (1979). Use of these models has significantly reduced the microturbulent velocities ($v_t$) required to produce abundances independent of equivalent width, when compared with results from unblanketed models.

In this review, logarithmic abundances are quoted on the scale log N(H) = 12.00. A few abundances will be quoted directly as ratios (e.g., Be, B).

### 2.2. Published Analyses of Normal A and B Stars

Adelman and Nasson (1980) studied θ Aql (B9.5 III), ν Cap (B9.5 V), and σ Aqr (A0 IVs) using 4.3 and 8.9 Å $mm^{-1}$ spectrograms. The first two stars were reported to have essentially solar compositions, but σ Aqr may belong to a "hot" extension of the Am sequence.

Sadakane (1981) studied two superficially normal stars, 21 Peg (B9.5 V) and HR 7338 (A0 III), using 2.4 Å $mm^{-1}$ spectrograms. He confirmed that 21 Peg has nearly solar abundances (actually it may have rather lower metal abundances if we accept Grevesse's compilation), but HR 7338 has remarkably low metal abundances, a conclusion not seriously affected by the presence of a binary companion.

Adelman (1984a) analyzed six slowly rotating normal mid- to late-B stars: π Cet (B7 V), 134 Tau (B9 IV), HR 2154 (B5 IV), HR 5780 (B6 IV), 21 Aql (B8 II-III), and ν Cap (again; see Adelman and Nasson 1980). Microturbulent velocities ranged from 0.0 to 1.8 km $s^{-1}$. He found essentially solar abundances in all six stars.

A few studies of specific elements in normal stars were conducted using ultraviolet spectra obtained with the Copernicus or International Ultraviolet Explorer (IUE) satellites. These studies were sometimes done as comparisons for chemically peculiar stars.

Boesgaard and Praderie (1981) analyzed the B II resonance line at 1362.46 Å in γ Gem (A0 IV) and found boron to be depleted by a factor 5-10 relative to other normal A and B stars studied earlier by Boesgaard and Heacox (1978). In that earlier study, a mean normal-star abundance relative to hydrogen of $1.4 \times 10^{-10}$ (LTE) was found, although the scatter was considerable. Boesgaard and Praderie also found that B II was undetectable in α CMa. They considered non-LTE corrections which raised the average abundance estimate to $2 \times 10^{-10}$.

Boesgaard and Praderie (1981) also studied merged 3.4 Å $mm^{-1}$ spectrograms of the Be II resonance line region at 3130-31 Å and found that beryllium in γ Gem is also depleted relative to the solar value (Be/H = $1.3 \times 10^{-10}$) by at least a factor of 4, while it seems to be normal in α Lyr.

Sadakane *et al* (1983) studied the Al II and Al III resonance lines in seven normal stars for comparison with chemically peculiar stars. They concluded that aluminium was close to the solar abundance in all the stars except α Lyr (see below).

Adelman and Leckrone (1984) presented a discussion of IUE spectra of π Cet, 134 Tau, and ν Cap. They pointed out the importance of the new laboratory work on atomic spectra for UV astronomy. They found that, while 134 Tau and ν Cap have essentially normal abundances of manganese, π Cet has a Mn abundance at least 0.6 dex higher, based on their preliminary IUE analysis.

## 2.3. Vega (α Lyr)

This bright star has, in the recent past, often been used as a normal comparison standard for differential analyses. It has become increasingly clear during the review period that Vega is metal-weak compared to most other normal B and A stars. It is also surrounded by a dust shell (Aumann *et al*, 1984) which is probably composed of large grains; this shell may be a disk seen face-on, so that it is entirely possible that Vega is a rapid rotator seen nearly pole-on (assuming that the rotational angular momentum vector is perpendicular to the disk). There is also increasing evidence for the disturbing possibility that Vega, which is the primary astronomical spectrophotometric standard, is slightly variable on occasions, and possibly shows low-amplitude δ-Scuti behaviour (Fernie, 1981). To compound the likelihood that Vega is indeed doing odd things, Goraya and Singh (1983) reported Hα variability (a transient emission) on 1983 October 12 on a time scale of 1.5 hr. Charlton and Meyer (1985) were not able to confirm this behaviour on six nights in 1984 August. Further observations are clearly essential due to the transient nature of the phenomenon.

Several abundance analyses of Vega may now be considered. Dreiling and Bell (1980) obtained high signal-to-noise Reticon spectra and analyzed the abundances of Ti and Fe; for iron they calculated "astrophysical" gf-values based on the solar spectrum. Their LTE analysis gave $v_t$ = 2.5 km $s^{-1}$, log N(Ti) = 4.7, log N(Fe) = 6.9 for Fe I and 7.1 for Fe II, depending on which set of oscillator strengths were used. An attempt to correct for non-LTE effects suggested that more nearly solar values would thereby be obtained, but this reviewer notes that other LTE results, e.g., those of Adelman, Sadakane, and their co-workers, should correspondingly be adjusted upwards, and this would produce embarrassing high abundances of Fe in many apparently normal stars. While Dreiling and Bell used observations of Vega in the region 4000 - 5000 Å, Sadakane and Nishimura (1981) compared results in the near UV (3250 - 3640 Å) with results in the visible (3900 - 4900 Å) to determine whether the same abundances and microturbulences would be obtained. They found $v_t$ = 2.0 km $s^{-1}$ in both regions, and log N(Fe) = 7.0 and 7.1 in the near UV and visible, respectively.

Most other metals also yielded low abundances in Vega when compared with the Sun, especially aluminium: Sadakane and Nishimura obtained log N(Al) = 5.5 in Vega, vs. 6.5 in the Sun and 6.14 in ν Cap (the A-star results are from analysis of the Al I resonance lines). The optical results, including those of Adelman (1984a) were confirmed in the UV analysis of the resonance lines of Al II and Al III by Sadakane, Takada, and Jugaku (1983) in several normal stars. They found that these two ions give essentially the same abundance results as the optical analyses of Al I. The fact that the resonance lines of all three ions give a very similar low abundance in Vega when analyzed by LTE techniques, while giving consistent solar or near-solar abundances in several other normal A and B stars, makes it difficult - if not impossible - to explain the observed deficiency in Vega by non-LTE effects.

Lambert, Roby, and Bell (1982) used high signal-to-noise Reticon observations in the visible and near infrared to study C I, N I, and O I in Vega. They concluded that the abundances of these elements are essentially the same as in the Sun.

Boesgaard and Praderie (1981) studied the Be II resonance line region in Vega with high signal-to-noise Reticon data (3100 - 3175 Å). Their analysis gave Be/H = 1 x $10^{-11}$, a value close to the average for other normal stars.

Friere Ferrero *et al* (1983) analyzed Mg II h and k profiles in Vega based on Copernicus and balloon ultraviolet spectra. Although the unblanketed model atmospheres adopted by them may be open to criticism, they obtained log N(Mg) = 7.0, in agreement with the results of Sadakane and Nishimura (1979), who found that Mg was somewhat underabundant (by a factor of 4) in Vega compared with the Sun. Welsh *et al* (1983) published UV balloon spectra of Vega in the region 2000 - 3200 Å but did not carry out a detailed analysis.

## 3. Hg-Mn STARS: ABUNDANCES

### 3.1. Element by Element

The study of Hg-Mn stars has been undergoing the same kind of revolution as other stellar studies, due largely to the availability of ultraviolet spectra from the IUE satellite. In this section, I will deal first with abundance studies of individual elements (in order of atomic number).

### 3.1.1. Be and B

Sadakane and Jugaku (1981) found that boron is strongly enhanced in κ Cnc, HR 7361, and 20 Tau (Maia in the Pleiades, B7 III). The latter star may be related to the Hg-Mn stars; it is not a "classic" Hg-Mn star since Hg is not present and Mn only mildly enhanced. They found both B II 1362 Å and the B III 2065-67 Å doublet. Leckrone (1981) determined an overabundance of B of about 2.5 dex in κ Cnc, but the B II resonance line was absent in μ Lep, 46 Dra, ι CrB, HR 4072, and χ Lup. Sadakane and Jugaku also found the Be II 3130-31 Å lines in HR 6997, HR 7361, κ Cnc, and 112 Her, which indicated a large enhancement of beryllium.

Boesgaard *et al* (1982) used 6.7 Å $mm^{-1}$ spectra taken at Mauna Kea to study 43 Hg-Mn stars and compare them with normal stars. They concluded that there is a trend for Be II lines to be enhanced when Mn II lines are enhanced. A temperature trend may be indicated: only half the cool Hg-Mn stars ($T_{eff} \lesssim 11000$ K) studied have enhanced Be II, while all hot Hg-Mn stars in their sample have enhanced lines of this element. The overabundance factors range from 20 to $2 \times 10^4$.

### 3.1.2. Al

Sadakane, Takada, and Jugaku (1983) analyzed the Al II and Al III resonance lines in 22 Hg-Mn stars using IUE spectra. The cooler Hg-Mn stars have moderate deficiencies of aluminium (0.5 to 1.0 dex), while the hotter Hg-Mn stars have deficiencies of about 1.4 dex.

### 3.1.3. Cu

Jacobs and Dworetsky (1981) found that copper is enhanced in 10 of 11 Hg-Mn stars studied. A temperature trend of increasing abundance was found for all Hg-Mn stars except 112 Her, which, perhaps paradoxically, appears to have a strong deficiency of Cu. The maximum overabundance found was nearly a factor $10^3$ (in HR 7361) compared to the Sun.

### 3.1.4. Ga

The remarkable gallium overabundance discovered many years ago in the hotter Hg-Mn stars at optical wavelengths has received spectacular confirmation through ultraviolet observations with IUE. Jacobs and Dworetsky (1981) confirmed the anomaly by observing the strong 1414 Å resonance line of Ga II in 7 out of 10 Hg-Mn stars, as well as two other Ga II lines. Takada and Jugaku (1981) presented broadly similar results in somewhat more detail for resonance lines of both Ga II and Ga III in several other stars. However, there is some disagreement between the two papers about the exact abundances giving rise to the observed lines;

Takada and Jugaku obtained lower Ga abundances by about 0.3 dex from Ga II and by about 0.5 dex from Ga III. These differences may reflect the somewhat preliminary nature of the analyses, rather than any profound physical problems or non-LTE effects. Jacobs (in preparation) has reconsidered the Ga abundance question and concludes that there are no significant differences between results from the two ions. The overabundance of gallium, in the Hg-Mn stars which have it, is of the order of $10^3$ - $10^4$.

### 3.1.5. Pt

Dworetsky, Storey, and Jacobs (1984) presented theoretical oscillator strengths for strong Pt II transitions in the ultraviolet, together with a spectrum synthesis analysis of the abundance of Pt in three cool Hg-Mn stars, χ Lup, HR 4072, and HR 7775, based on IUE spectra. The least blended lines are 1777 Å and 2144 Å. The abundances found range from log N(Pt) = 6.0 in χ Lup to 6.6 in HR 7775. The solar abundance is 1.8, so the enhancement factor for platinum is of the order of $2\times10^3$ to $10^4$. "Astrophysical" gf-values for Pt II lines in the optical region were also obtained.

### 3.1.6. Hg

Dworetsky (1980a) used published data to show that the oscillator strength of Hg II 3984 Å was obtainable from laboratory experiments. He also showed that the discussions of IUE observations of the Hg II resonance lines at 1942 Å and 1649 Å by Leckrone (1980) led to an abundance of mercury in agreement with those from 3984 Å and from the Hg I line at 4358 Å in the same stars, when LTE analyses were employed. Leckrone (1984) has reconsidered the entire problem in great detail, taking into account the well-known isotopic anomalies in Hg II and the observed splitting of the 3984 and 1942 Å lines (Guern *et al* 1976). The earlier work is confirmed: the results for LTE calculations now yield excellent agreement between Hg I and Hg II lines, when mercury is assumed to be homogeneously distributed in the atmosphere.

Mégessier, Michaud, and Weiler (1980) stated that they had found Hg in the first three stages of ionization in two Hg-Mn stars, μ Lep and χ Lup. Since these stars have very different $T_{eff}$ (13000 and 11000 K, respectively), they argued that this could only happen if Hg were concentrated (by diffusion processes) in a thin layer at small optical depths, rather than homogeneously distributed. Leckrone (1984) showed that their identification of Hg II suffered from a wavelength calibration error. This suggests that their identification of Hg III may also be in error. Jacobs and Dworetsky (1981) searched for Hg III in a differential comparison of IUE spectra of two Mn stars (53 Tau and φ Her); φ Her has strong Hg II and 53 Tau, remarkably, has none. No credible evidence for Hg III was found nor was any found in the hot Hg-Mn star HR 7361, where it might have been expected.

Leckrone (1984) also discussed the enhancement factor for mercury in Hg-Mn stars. The five stars he studied all yielded abundances of the order of log N(Hg) = 6.0. The meteorite abundance given by Grevesse (1984) is log N(Hg) = 1.27, which is poorly determined, while a solar spectroscopic determination is probably not possible. Leckrone tentatively determined log N(Hg) = 2.1 from his analysis of the normal stars ν Cap and π Cet. Due to the weakness of the lines seen, this is likely to be an upper limit. If Leckrone's result is more representative of normal stellar compositions, the gross enhancement factor for Hg is typically $10^4$ ; if the meteorite value is more correct, enhancements of 4 x $10^4$ to $10^5$ are representative. In the cool Hg-Mn stars, large enrichments of $Hg^{204}$ are seen relative to other isotopes: the enhancement of this isotope may therefore reach values of $10^6$ or more.

### 3.1.7. Bi

Jacobs and Dworetsky (1982) found that bismuth was extraordinarily strong in HR 7775 but absent in all other Hg-Mn and normal stars which they studied. They used spectrum synthesis to determine log N(Bi) = 6.7 to 6.8. The solar system abundance is from meteorites only: log N(Bi) = 0.7. Here, Bi is enhanced by a factor of $10^6$ , which is the largest factor for any element so far obtained. Guthrie (1984) found a strong, broad line ($W_\lambda$ = 36 mÅ) at 4259.41 Å in DAO coudé spectra of HR 7775 which does not occur in other Hg-Mn stars; it is almost certainly a Bi II feature.

## 3.2. Abundances in Individual Stars

Several abundance analyses were published during the review period, and are described briefly below.

### 3.2.1. α And

Derman (1982) published a new analysis of α And based on 7 and 12 Å $mm^{-1}$ spectra obtained at Haute Provence by Hack and Stalio. This analysis, like many others, suffers from imprecision due to the high rotational velocity of the star. Derman points out that $T_{eff}$ estimates for α And differ widely. His results confirm the long-held view that the chief anomalies are overabundances of P, Mn, Ga, Sr, Y, Zr, and Hg. Derman also reminds us that several previous investigators suspected that α And is surrounded by a circumstellar shell and that light and spectrum variations have been claimed by several authors.

Derman did not include mention of the paper by Rakos, Jenkner, and Wood (1981) in which further evidence of photometric and spectroscopic variations with P = 0.9636 days was presented, based on Copernicus data.

### 3.2.2. 33 Gem

Chunakova, Bychkov, and Glagolevskij (1981) give preliminary photographic magnetic field results for this star. The variation is roughly sinusoidal with a total range of 3 kGs and P = 3.099 days. Why is a magnetic Ap star discussed in this review? According to the authors, 33 Gem has Hg II 3984 Å, Mn II, and P II as well as features which correspond to those of the Si stars, and demonstrates that it is possible for Hg-Mn characteristics to appear occasionally in magnetic Ap stars.

### 3.2.3. HR 562 = HD 11905

This star has recently been analyzed by Ptitsyn and Ryabchikova (1986) using 8 Å $mm^{-1}$ spectra obtained with the Bulgarian 2-m telescope. In most respects, the authors find HR 562 to have typical Hg-Mn abundances, except that the iron abundance is lower than solar by 0.9 dex! There is a suggestion that asymmetries in the line profiles may be due to a binary companion. HR 562 also seems to belong to the small subgroup of Hg-Mn and related objects with deficiencies of C and/or Si.

### 3.2.4 υ Her and 38 Dra

Adelman (1984b) gives a new analysis of υ Her based mainly on Mt. Wilson spectrograms. This star is a "classic" Hg-Mn type, with deficiencies of He, Mg, and Ni, roughly normal Na, Si, S, Ca, Sc, Cr, and Fe, and large enhancements of P, Mn, Ga, Sr, Y, and Hg.

Adelman also rediscusses the earlier analysis of the high velocity Hg-Mn star 38 Dra by Adelman and Sargent (1972). This star is also typical, although quantitatively different. Carbon was not detected, Ca is deficient, while Sc, Mn, and Sr are enhanced only by 1 dex and Ni is normal. Gallium was not observed, but Y and Zr are enhanced by about 2 dex. This is in contrast to υ Her: Adelman did not detect Zr II in that star. Again, Hg II 3984 Å is very strong. Adelman finds that Ba is enhanced in 38 Dra by about 2 dex over the solar value.

### 3.2.5. ν Cnc

Adelman, Young and Baldwin (1984) carried out a detailed analysis of the Hg-Mn star ν Cnc. This star is of interest because, with $T_{eff}$ = 10375 K, log g = 3.60, it may be the coolest of the "classical" Hg-Mn stars, only a few hundred degrees hotter than Sirius. Besides the now-familiar anomalies associated with Hg-Mn stars, it has a strong Sc enhancement and a mild Ni enhancement, relative to solar abundances.

### 3.2.6. Guthrie's Survey

Guthrie (1984) performed a differential curve-of-growth analysis of 20 of the sharpest-lined Hg-Mn stars based on published equivalent widths, on 2.4 Å $mm^{-1}$ DAO spectrograms loaned by Prof. C. R. Cowley, or on Edinburgh 6 Å $mm^{-1}$ spectrograms. The comparison star was γ Gem (A0 IV). Among the more interesting conclusions are these:

1) Mg is very underabundant in some stars;
2) Sc has large star-to-star differences;
3) V may be deficient in at least some cases;
4) Ni is generally deficient;
5) the Pt II isotope shift in HR 1800 is nearly as large as that in χ Lup, and the Pt overabundance phenomenon is confirmed

as confined to the very narrow range of temperatures, 11000 K < $T_{eff}$ < 12000 K;

6) the presence of Au and Bi is confirmed in HR 7775; it seems likely that Au is present in the atmospheres of HR 4072 and χ Lup primary stars as well.

## 4. RELATED STARS: SPECTRA AND ABUNDANCES

In this section I review publications on intermediate-temperature stars which are (or may be) related to the Hg-Mn phenomenon. Sirius (α CMa) is included because its $T_{eff}$ is very close to the lower limits of the Hg-Mn range.

### 4.1. Sirius (α CMa)

Boesgaard and Praderie (1981) found that Sirius is strongly deficient in Be and B. For both elements, their analysis gave upper limits well below the normal-star abundances.

Bell and Dreiling (1981) analyzed Fe I, Fe II, and Ti II lines in LTE and concluded that log N(Ti) = 5.5, log N(Fe) = 8.0 and 8.1 from Fe I and Fe II, respectively.

Lambert, Roby, and Bell (1982) examined the C, N, O abundances in Sirius, based on visual and infrared Reticon spectra. Although they found that these elements had essentially solar abundances in Vega (see 2.3 above), in Sirius they found a strong C deficiency (-0.6 dex), a mild O deficiency (-0.3 dex), and a slight N excess (0.2 dex).

### 4.2. 20 Tau

This Pleiades star is Maia, HD 23408, B7 III. It had previously been classified as He-weak and has the smallest v sin i of any B star in the Pleiades cluster (45 km $s^{-1}$). Several analyses had been done previously; during the review period Mon, Hirata, and Sadakane (1981) published their new analysis. They find He to be very weak (-0.7 dex); Mg, Si, Ca, Ni to be underabundant (especially Si, -1.1 dex); C, Ti, Cr, Fe to be normal; and P, Mn to be overabundant (0.8 and 0.7 dex, respectively). It appears that this Pleiades star has many characteristics of mild Hg-Mn stars. This conclusion is strengthened by Sadakane and Jugaku (1981), who found a large enhancement of B in 20 Tau similar to that seen in κ Cnc and other Hg-Mn stars, and probable enhancement of Be. The Be enhancement in 20 Tau is, in all probability, rather marginal (about 1.0 dex), according to Boesgaard *et al* (1982). In addition, Sadakane, Takada, and Jugaku (1983) found that Al II and Al III lines in the ultraviolet spectrum indicate a deficiency of -1.2 dex, typical of Hg-Mn stars. The reader may care to note that, by 1982, several astronomers had routinely included 20 Tau in their samples of Hg-Mn stars for survey purposes.

## 4.3. HR 6000

Five papers on this important and most unusual star (= HD 144667) were published during the review period. The brief paper by Castelli, Cornachin, and Hack (1981) on the ultraviolet spectrum has been superseded by a more detailed analysis by Castelli *et al* (1984, 1985) and new optical spectroscopy is discussed by Andersen and Jaschek (1984) and Andersen, Jaschek, and Cowley (1984). A most important item concerning this remarkable object is the strong likelihood that it is extremely young: it is a visual common-proper-motion companion of the A7 IIIe star HR 5999 which is associated with a T Tauri group and a reflection nebula. If the connection is indeed proven, then this Ap star must have an age somewhat less than $10^6$ yr. To the best of my knowledge no magnetic field observations of HR 6000 have been published. It remains to be seen whether or not HR 6000 has a magnetic field. The radial velocity is constant (Andersen and Jaschek, 1984).

The optical and ultraviolet results are in reasonable agreement about the main abundance anomalies. The authors quoted above agree that $T_{eff} \simeq 14000$ K, although opinions differ concerning surface gravity. (A new calibration of the Stromgren parameters $c_0$ and $\beta$ by Moon and Dworetsky (1985) gives $T_{eff} = 14070$ K, log g = 4.28, indicating that HR 6000 is on the zero-age main sequence.) The most striking anomalies are, along with the usual He weakness, large underabundances of Si and C. Lines of these elements are totally absent in the optical spectrum (limit 10 - 15 mÅ), while the ultraviolet results suggest underabundances of 2 - 3 dex. Underabundances of N and Al are also reported by Castelli *et al* (1985). The Fe II lines in the optical spectrum are very strong; P and Mn are mildly enhanced (1 dex). There is some evidence that Xe is enhanced. Although HR 6000 bears some resemblance to Hg-Mn stars, the optical and ultraviolet observations showed that Hg II lines are absent or very weak. The Ga II line at 1414 Å illustrated by Castelli *et al* (1985) is very weak when compared to the same line in Hg-Mn stars which have gallium anomalies, and may be identical to an unidentified feature at nearly the same wavelength which is also seen in normal stars (J. Jacobs, priv. comm.).

Castelli *et al* (1985) also report that resonance lines of C II, O I, Mg II, Si II, and Fe II appear to have circumstellar or interstellar components shifted by $-15$ km $s^{-1}$.

## 4.4. Superficially-Normal Late B Stars

Cowley (1980) presented 2.4 Å $mm^{-1}$ spectroscopic observations of 13 sharp-lined late B stars. All but one had spectra which, at classification dispersions, showed no obvious line-strength anomalies. Cowley classed 46 Aql and 23 Cas as "mild" Hg-Mn stars on the basis of his high-dispersion spectra. For example, a weak Hg II line is visible in 46 Aql, and both stars have marked P II enhancements. The star 21 Peg may be a hot analogue of the Am stars. The case of 64 Ori is more complicated: this is a spectroscopic triple system consisting of a double, sharp-lined, short-period binary and a third component with broad lines. The rest of the sample studied seems to consist of relatively normal stars. Sadakane (1981) did a detailed study of 21 Peg and HR 7338 using Cowley's spectrograms and concluded that, in fact, 21 Peg has abundances within 0.3 dex of the solar values, while HR 7338 is clearly metal-deficient to a degree even more pronounced than Vega.

### 4.5. HOT Am STARS: o Peg and $\sigma$ Aqr

Adelman, Young, and Baldwin have carried out analyses of these two hot Am stars ($T_{eff}$ = 9625 K and 10125 K, respectively). They appear to have a significant He deficiency, while most of the metals are slightly enhanced. Also, Ni, Sr, Zr, and Ba are enhanced by about 1.0 dex.

## 5. STATISTICAL STUDIES OF LINE STRENGTHS

Cowley and Aikman (1980) studied wavelength coincidence statistics (WCS) and showed that, in many cases, WCS based on the measurement of high-dispersion spectra can give valid, though crude, estimates of photospheric abundances (they quote ± 0.5 dex). In other words, one can not only identify which elements are present by statistical means, but one can also obtain approximate quantitative information. They calibrated their statistical parameters with adopted model-atmosphere abundances of Cr, Mn, Fe, and Y for normal and chemically peculiar stars.

In a very important paper, Cowley, Sears, Aikman, and Sadakane (1982) studied WCS for a sample of 34 late B and early A stars. They pointed out that effects due to $T_{eff}$ and v sin i could be allowed for quite well (see their Fig. 1), and that the results clearly suggest that Fe is underabundant in several stars in their sample (HR 562, HR 8226, Vega). Somewhat surprisingly, perhaps, the known metal-weak A0 III star HR 7338 (Sadakane, 1981) did not show any indication from the statistical study that Fe was underabundant. The Fe lines may be enhanced because of the much lower surface gravity of this star. On the other hand, the recent study of HR 562 by Ptitsyn and Ryabchikova (1985) confirms the remarkable weakness of the Fe II spectrum. The enhancement of Fe II in Sirius shows up clearly in the WCS results.

Bord and Davidson (1982) applied WCS techniques to the long-wavelength IUE spectrum of $\kappa$ Cnc (1850 - 3250 Å). As might be expected in a hot Hg-Mn star, they found clear evidence for Fe II, Mn II, and Cr II. Os II was also detected "possibly". A further study of the same spectrum by Davidson and Bord (1982) produced marginal evidence for the presence of Si II, Cl II, Ca II, Sr II, and Zr II.

Chjonacki, Cowley, and Bord (1984) applied the quantitative WCS technique developed by Cowley and Aikman to the ultraviolet IUE spectrum of $\kappa$ Cnc in both the SWP and LWR regions (1223 - 2097 Å; 1969 - 3227 Å), and examined the results for Fe II, Fe III, Mn II, and Mn III. They concluded that Fe III and Mn III lines were clearly present, and that any departures from the Saha ionization equilibrium must be small. They also concluded that, within the admittedly large uncertainties (0.3 - 0.5 dex) of their results, the Fe and Mn abundances are equal.

Finally, Bord and Davidson (1985) have used WCS techniques to demonstrate that reasonably accurate stellar radial velocities can be obtained from IUE spectra of sharp-lined stars. The studied κ Cnc, ι CrB, $\alpha^2$ CVn, and χ Lup. In the case of χ Lup, a double-lined spectroscopic binary, they obtained a clear detection of both the primary and the secondary spectra, even though the secondary star is approximately 1.5 mag fainter.

## 6. MAGNETIC FIELDS: UPPER LIMITS

It has been assumed implicitly throughout this review that normal late B stars and Hg-Mn stars do not, in fact, have measurable magnetic fields. During and shortly before the review period, two papers were published which formally confirm this assumption. Landstreet (1982) used photoelectric Zeeman techniques to search for longitudinal magnetic fields in 36 bright upper-main-sequence stars; of these, 9 are in or near the temperature range for this review. In no case did Landstreet record significant detection of a magnetic field. Among the best-observed cases is Vega (α Lyr) with B = -9 ± 19 Gs; the median error for all of Landstreet's observations is ± 65 Gs. Borra and Landstreet (1980) previously used similar techniques to study 6 Hg-Mn stars. In no case was a significant field detected, with typical errors of ± 170 Gs. The bright Hg-Mn star α And was observed on 5 of 6 successive nights, with no significant detection of a magnetic field (average error ± 50 Gs). One other Hg-Mn star, ι CrB, was previously observed by Borra, Landstreet, and Vaughan (1973) with null results of the same precision.

## 7. LINE ASYMMETRIES

Rice and Wehlau (1982, 1984) have published the results of careful searches for line asymmetries of Fe II lines in the Hg-Mn stars ι CrB, φ Her, and κ Cnc, with negative results. Previously, Dworetsky (1980b) had shown that the asymmetries observed in ι CrB by Smith and Parsons (1976) were due to the binary nature of this star. Weak asymmetries of Hg-Mn line profiles might be expected on theoretical grounds (Michaud, 1978).

## 8. RADIAL VELOCITIES

Radial-velocity data for 96 Hg-Mn stars (or candidates which turn out to be normal) have been published by Stickland and Weatherby (1984). This compilation is based on 8.6 Å $\mathrm{mm}^{-1}$ plates taken at the Royal Greenwich Observatory. Several new orbits are proposed. Further discussion of the remaining literature on radial velocities and orbits is somewhat beyond the scope of this review.

## 9. SPECTROPHOTOMETRY

Adelman and Pyper (1983) presented additional spectrophotometry of 4 Hg-Mn stars and 3 other Ap stars to augment their earlier data for 11 Hg-Mn stars (Adelman and Pyper, 1979). These and other results are brought together and discussed by Adelman (1984c). In that paper, Adelman considers peculiarity indices centred on 3509 Å, 4200 Å, 5200 Å and 6300 Å. These are defined in terms of the spectrophotometric data given in the series of papers by himself and colleagues Pyper and White begun in 1979.

There are difficulties in comparing spectrophotometrically-defined indices with narrow-band photometric indices. For example, at different times Adelman has used three separate indices to study the 4200 Å feature (although one has been rejected as not very sensitive). He has also tried two different definitions of Δa, the 5200 Å parameter, and considers the use of an equivalent width measurement for this feature based on spectrophotometry.

There are structural differences in the 5200 Å feature in various Hg-Mn stars, best appreciated in Adelman's Fig. 11. It is still not clear what causes the 5200 Å feature to be strong only in some Hg-Mn stars and in nearly all magnetic Ap stars.

## 10. LAMBDA-BOÖTIS STARS

After many years of "non-status" λ Boo stars have once again attracted the attention of astronomers interested in chemical peculiarities. Hauck and Slettebak (1983) offer a spectroscopic definition: "λ Boo stars are A-F type stars with metallic lines which are too weak for their spectral types, when the latter are determined from the ratio of their K-line to Balmer-line strengths. They are distinguished from weak-lined Population II (horizontal branch) stars by the fact that they have normal space velocities and moderately large rotational velocities." In fact, the λ Boo phenomenon seems to extent to B9, as ε Sgr is listed by Hauck and Slettebak as a λ Boo star; thus the phenomenon extends to sufficiently hot stars that it may be included in this review.

Baschek *et al* (1984) have examined the ultraviolet spectra of λ Boo stars. There are indications of a normal carbon abundance; also, there is a strong broad unidentified feature at 1600 Å in λ Boo stars which is absent in normal stars. Paradoxically, they find that the λ Boo star 29 Cyg is only marginally of this type in the ultraviolet, while ρ Vir is a λ Boo star in the ultraviolet but fairly normal in the optical! Further characteristics are weak Al II and Mg II in the ultraviolet.

Morgan (1984) and Abt (1984) presented interesting discussions of a remarkable extreme metal-weak A star, HR 4049. All that can be seen in the optical spectrum 3900 - 4900 Å (at 39 Å $mm^{-1}$) are narrow H lines and a weak Ca II K-line; Morgan remarked that "no MK box...can accept the spectrum..." which has been assigned the type A0 Ib-IIpec. (The luminosity may be too high to fit the usual λ Boo type, but what is it?)

Abt (1984) also described his search for stars near A0 with weak Mg II lines. Only a very few have $(B - V) \lesssim 0.00$; one (20 Eri) is very blue $(B - V \simeq -0.13)$. In the discussion after his paper, Abt pointed out that nothing was known about the binary frequency of these stars.

## 11. ANOMALOUS C IV AND Si IV LINES

Sadakane (1984) reported the startling news that high-resolution IUE spectra of 36 Lyn exhibits strong, broad resonance absorptions of

C IV and Si IV. Although 36 Lyn is a magnetic He-wk Bp star with Teff = 13,600 K and is not a Hg-Mn star, it seems worthwhile to call this remarkable phenomenon to the attention of astronomers. Sadakane concludes that these lines can not be photospheric and probably originate in a circumstellar corona or chromosphere.

Molaro *et al* (1983) found similar anomalous C IV and Si IV lines in the rapidly rotating A0 V star HD 119921 (HR 5174), which they find to be blue-shifted by nearly 70 km $s^{-1}$ with a shortward absorption asymmetry. Variable broad C IV and Si IV resonance absorptions are often found in Be stars as well (e.g., Barker and Marlborough, 1985).

The possibility that 36 Lyn has a companion should not be ruled out, although there is no direct evidence for binarity. If it had a rapidly rotating companion whose expanding envelope surrounded both stars, an explanation for the anomalous lines might readily be imagined. A careful search for $H_\alpha$ emission in 36 Lyn might be worthwhile.

## 12. OPEN CLUSTERS

Klochkova (1983) examined the peculiar stars in the Pleiades at 9 Å $mm^{-1}$. She confirms that HD 23950 (HR 1185) is a Hg-Mn star (see Abt and Levato, 1978) although she did not comment on the shell-like nature of the spectrum which Abt and Levato mention (see below).

Mermilliod (1982, 1983) provides some remarkable insights into cluster stars. In the 1982 paper, he looked at the available data on blue stragglers and concluded that, in "middle-aged" clusters, the percentage of Ap's of all types among blue stragglers is very large. However, most of these seem to be He-wk and Si stars rather than Hg-Mn stars. In older clusters, blue stragglers are often Am stars.

In 1979, Abt published his very important summary of the occurrence of Ap stars in open clusters. He noted that a number of stars had characteristics of rapid rotators ("n" appended to spectral type) and simultaneously characteristics of slow rotators ("s" for sharp-lined). He suggested that these might be weak shell stars. A few of these are Ap stars of various types, including HD 23950, a Hg-Mn star.

In the 1983 paper, Mermilliod considered the "sn" stars in open clusters and associations. There are 17 cluster "sn" stars, and a further 12 in the Orion OB1 association. They have low values of v sin i, sharp lines of Ti II, Ca II, Si II, C II, and Fe II, and broad lines of He I, as if they had thin shells (i.e., Abt's original hypothesis). However, the "sn" stars often have He-weak or Hg-Mn characteristics; I have already mentioned the example of HD 23950; Maia (HD 23408; see 4.2) is another. Mermilliod considers that α Scl resembles "sn" stars if observed with resolutions comparable to that used by Abt. Mermilliod gives reasons why the "sn" stars are almost certainly intrinsic slow rotators and not pole-on, and argues that the "shell" hypothesis is an unlikely explanation of the appearance of the spectra. Discerning their true nature awaits better observations.

## 13. X-RAY OBSERVATIONS

Cash and Snow (1982) and Golub *et al* (1983) have published the results of observations of 51 A and late B stars with the Imaging Proportional Counter and (in a few cases) with the High Resolution Imager on the Einstein satellite. They attempted to detect 5 Hg-Mn stars, as well as several bright normal stars near A0 V. The essence of their conclusions may be stated as follows:

1) Single stars in this part of the HR diagram, whether normal or peculiar, generally emit soft X-rays (0.15 - 4.0 keV) in accordance with the scaling law for early-type stars, log $(L_X/L_{bol}) = -6.9$.
2) A-star binaries often have enhanced X-ray emission. This usually comes from active young late-type companions, or, in the case of Sirius (α CMa) from a hot white dwarf companion.
3) The coronal temperatures deduced from single stars near A0 V are quite low, $\leqslant 10^6$ K. In the case of ϕ Her, the previously reported detection with HEAO 1 (Cash, Snow, and Charles 1979) was either an error or the temperature is very low.

## 14. BINARITY, STATISTICS, AND SYSTEMATICS

Guthrie (1981) compared binary and single Hg-Mn stars statistically in order to test two possibilities: firstly, whether the (unknown) braking mechanism is more effective in short-period binaries; secondly, whether the hypothesis of Guthrie and Napier (1980) has any observed effect, namely, that in SB2's mutual irradiation would inhibit diffusion and lead to different abundances.

The results showed a highly significant difference in that SB2's and shorter-period SB1's rotate much more slowly than longer-period SB1's and single Hg-Mn stars. The problem is that, although the former group has experienced more tidal braking than the latter, several SB2 stars are rotating more slowly than their synchronous velocities.

In the second investigation, Guthrie found only one significant pattern: Sc tends to be weak or absent in SB2's, and strong in single stars and longer-period SB1's.

Eggen (1984) has carried out an extensive analysis of the MK spectral classification, uvbyβ photometry, and space motions (U, V, W) of field A0 stars in the Yale Catalogue of Bright Stars. Of much interest to us is his discovery that, due to the standards used, the "Houk" sample (i.e., the new Michigan catalogues) fit MK standard photometric boxes far better than the Cowley *et al* (1969) sample, which has the A0/A1 border well within the standards' A0 box.

Eggen's discussion of membership in moving groups is interesting, although perhaps controversial. His Hyades and Sirius "supercluster" groups contain a few Ap stars, and yield a high number of blue stragglers of which several are Ap's of various types. Whether or not this is a result of including higher luminosity Ap stars in the A0 sample might be a subject for further investigation.

## 15. MICROTURBULENCE: SOME NEW RESULTS

The usual way in which microturbulence is determined in a fine analysis is to plot log (Abundance) vs. $W_\lambda$, and choose that value of $v_t$

which makes abundances independent of line strength. Dufton, Durrant, and Durrant (1981) showed that this procedure leads to systematic overestimates of $v_t$ due to the non-linearity of the curve of growth, i.e., the random errors in $W_\lambda$ give rise to an adopted $v_t$ which is too large. The effect is particularly important for the light elements which they studied in B stars. Dworetsky (1982) showed that this effect can be reduced by using heavier elements like Fe. The fundamental problem remains, and a neat solution has been proposed by Magain (1984). The systematic error can be eliminated by plotting log (Abundance) vs. $W_\lambda$ (synthetic) for an assumed abundance, model, and $v_t$. One should then choose $v_t$ as before, but now, since the $W_\lambda$'s are theoretical, they do not contain random observational errors.

The use of fully-line-blanketed model atmospheres clearly leads to lower required values of $v_t$, as predicted by Kurucz. Dworetsky, Storey and Jacobs (1984) found that the values of $v_t$ obtained in analyses of HR 4072 and $\chi$ Lup using unblanketed models (2.0 km $s^{-1}$) were much higher than those obtained using blanketed models (0.9 km $s^{-1}$). Any published microturbulent velocity obtained with unblanketed models should be viewed with scepticism.

## 16. SUMMARY AND CONCLUSIONS

Dr Hack (1981), in her review paper for the Liège Colloquium, concluded with a discussion of what was known, what was unknown, and what needed to be studied more. To a remarkable extent, the points she raised then remain unanswered.

It is increasingly clear that the future for abundance determinations lies with high-quality observational material and detailed careful analysis. The virtually untouched problem of CNO abundances in late B and early A stars should be approached from both the optical (i.e., near infrared) and ultraviolet (for C, N) data. The optical study by Lambert, Roby, and Bell (1982) sets a demanding high signal-to-noise standard for future workers to emulate. There is still an enormous amount of work remaining to be done on the vast accumulation of IUE high-resolution spectra of both normal and chemically peculiar stars. Due to the extremely crowded nature of the spectra, it is important that only appropriate techniques such as spectrum synthesis be used.

The study of Hg-Mn and other peculiar stars in clusters needs to be taken a lot further. We urgently need to obtain high-resolution spectra of these stars, and normal stars in the same clusters, and analyze them carefully. It may be possible to identify age-dependent anomalies in this way. The observations can not be done photographically, because the stars are too faint; high-quantum-efficiency detectors must be used.

Photographic observations still play an important part in abundance analysis of A and B stars. The important remarks by Cowley and Adelman (1983) are relevant to their use; compared with only a few years ago, it is much more readily possible now to perform feats of numerical manipulation on digitized tracings to obtain co-added spectra of high signal-to-noise, and to use smoothing algorithms to obtain further improvements. I recommend that this paper be read by all workers in the field.

Although photographic spectroscopy is regarded as an obsolete technique in some astronomical circles, it remains largely true that very few high efficiency solid-state detectors are used with spectrographs which provide anything approaching the spectral resolution and coverage of the classical coudé spectrographs ($\lambda/\Delta\lambda = 10^5$ or better, over 1000 Å). One hopes that this situation will change, and there are encouraging signs in this direction.

We still do not know the nature of the braking mechanism which slows down Hg-Mn and related stars (presuming, of course, that these stars do not form as slow rotators; HR 6000 may be a case in point). Whatever it is, it seems to be exceedingly effective. Because it has now been demonstrated that the fields in these stars are non-existent or at least too weak to be detected at a noise level of 50 - 100 Gs, magnetic explanations seem increasingly unlikely.

It is becoming clearer that the Hg-Mn phenomenon concerns not only stars which are "fully formed" Hg-Mn objects, but that "marginally peculiar" stars with many similarities to them exist. Discovery of these objects is (by Dr Cowley's definition) virtually impossible from ordinary MK classification, unless one's suspicions are aroused by discrepant colours and He-types; one can readily see that selection processes will inhibit discovery of cooler members of this class (in fact, very few are known), because He lines would not be expected in any great strength anyways. Most often they are discovered accidentally during the course of other work. This promises to be an important and fruitful area for further investigations.

At the same time, it has also become clear that the range of metal abundances in "normal" late B and A0 stars is greater than expected. We now see quite plainly that Vega has normal (i.e., solar) CNO abundances, but is obviously metal-weak. On the other hand, Sirius, perhaps the prototype "early Am" star, has a "disturbed" CNO abundance pattern and a considerable metal enrichment. More and better detailed abundance analyses of normal stars near A0 are urgently needed; results of this quality for only two stars are woefully insufficient.

The revival of interest in the λ-Boötis stars is very welcome. We seem to know almost nothing about them. Here lies material for a dozen highly significant doctoral theses!

One new observational tool will become available, if all goes according to schedule, late in 1986. The Hubble Space Telescope High Resolution Spectrograph will be capable of producing spectra of resolution and signal-to-noise equal to the best available in the optical from coudé spectrographs. However, the amount of time expected to be available for stellar abundance studies will, regrettably, be small.

## REFERENCES

Abt, H. A. (1979). Astrophys. J., 230, 485.

Abt, H. A. (1984). In The MK Process and Stellar Classification, ed. R. F. Garrison (David Dunlap Obs., Toronto), p. 340.

Abt, H. A., and Levato, H. (1978). Publs. Astron. Soc. Pacific, 90, 201.

Adelman, S. J. (1984a). Mon. Not. R. Astron. Soc., 206, 637.

Adelman, S. J. (1984b). Astron. Astrophys. Suppl., 58, 585.

Adelman, S. J. (1984c). Astron. Astrophys. Suppl., 55, 479.

Adelman, S. J., and Leckrone, D. S. (1984). Physica Scripta, T8, 25.

Adelman, S. J., and Nasson, M. A. (1980). Publs. Astron. Soc. Pacif., 92, 346.

Adelman, S. J., and Pyper, D. M. (1979). Astron. J., 84, 1603.

Adelman, S. J., and Pyper, D. M. (1983). Astron. Astrophys., 118, 313.

Adelman, S. J., and Sargent, W. L. W. (1972). Astrophys. J., 176, 671.

Adelman, S. J., Young, J. M., and Baldwin, H. E. (1984). Mon. Not. R. Astron. Soc., 206, 649.

Anders, E., and Ebihara, M. (1982). Geochim. Cosmochim. Acta, 46, 2363.

Andersen, J., and Jaschek, M. (1984). Astron. Astrophys. Suppl., 55, 469.

Andersen, J., Jaschek. M., and Cowley, C. R. (1984). Astron. Astrophys., 132, 354.

Aumann, H. H., Gillett, F. C., Beichman, C. A., de Jong, T., Houck, J. R., Low, F. J., Neugebauer, G., Walker, R. G., and Wesselius, P. R. (1984). Astrophys. J., 278, L23.

Barker, P. K., and Marlborough, J. M. (1985). Astrophys. J., 288, 329.

Baschek, B., Heck, A., Jaschek, C., Jaschek, M., Koppen, J., Scholz, M., and Wehrse, R. (1984). Astron. Astrophys., 131, 378.

Bell, R. A., and Dreiling, L. A. (1981). Astrophys. J., 248, 1031.

Boesgaard, A. M., and Heacox, W. D. (1978). Astrophys. J., 226, 888.

Boesgaard, A. M., Heacox, W. D., Wolff, S. C., Borsenberger, J., and Praderie, F. (1982). Astrophys. J., 259, 723.

Boesgaard, A. M. and Praderie, F. (1981). Astrophys. J., 245, 219.

Bonsack, W. K., and Wolff, S. C. (1980). Astron. J., 85, 599.

Bord, D. J., and Davidson, J. P. (1982). Astrophys. J., 258, 674.

Bord, D. J., and Davidson, J. P. (1985). Astron. Astrophys., 143, 461.

Borra, E. F., and Landstreet, J. D. (1980). Astrophys. J. Suppl., 42, 421.

Borra, E. F., Landstreet, J. D., and Vaughan, A. H. (1973). Astrophys. J., 185, L145.

Cash, W., and Snow, T. P. (1982). Astrophys. J., 263, L59.

Cash, W., Snow, T. P., and Charles, P. (1979). Astrophys. J., 232, L111.

Castelli, F., Cornachin, M., and Hack, M. (1981). In Upper Main Sequence CP Stars, 23rd Liège Astrophys. Colloq. (Univ. Liège), p. 149.

Castelli, F., Cornachin, M., Hack, M., and Morossi, C. (1984). Astron. Astrophys., 141, 223.

Castelli, F., Cornachin, M., Hack, M., and Morossi, C. (1985). Astron. Astrophys. Suppl., 59,1.

Charlton, J. C., and Meyer, B. S. (1985). Publs. Astron. Soc. Pacif., 97, 60.

Chjonacki, G. T., Cowley, C. R., and Bord, D. J. (1984). Astrophys. J., 286, 736.

Chunakova, N. M., Bychkov, V. D., and Glagolevskij, Yu. V. (1981). Soob. Sp. Astrofiz. Obs., 31, 5.

Cowley, A., Cowley, C., Jaschek, M., and Jaschek, C. (1969). Astron. J., 74, 375.

Cowley, C. R. (1980). Publs. Astron. Soc. Pacif., 92, 159.

Cowley, C. R., and Adelman, S. J. (1983). Q. J. R. Astron. Soc., 24, 393.

Cowley, C. R., and Aikman, G. C. L. (1980). Astrophys. J., 242, 684.

Cowley, C. R., Sears, R. L., Aikman, G. C. L., and Sadakane, K. (1982). Astrophys. J., 254, 191.

Davidson, J. P., and Bord, D. J. (1982). Astron. Astrophys., 111, 362.

Derman, I. E. (1982). Astrophys. Space Sci., 88, 135.

Dreiling, L. A., and Bell, R. A. (1980). Astrophys. J., 241, 736.

Dufton, P. L., Durrant, A. C., and Durrant, C. J. (1981). Astron. Astrophys., 97, 10.

Dworetsky, M. M. (1980a). Astron. Astrophys., 84, 350.

Dworetsky, M. M. (1980b). Mon. Not. R. Astron. Soc., 191, 521.

Dworetsky, M. M. (1982). A Peculiar Newsletter, No. 9, p.3.

Dworetsky, M. M., Storey, P. J., and Jacobs, J. M. (1984). Physica Scripta, T8, 39.

Eggen, O. J. (1984). Astrophys. J. Suppl., 55, 597.

Fernie, J. D. (1981). Publs. Astron. Soc. Pacif., 93, 333.

Friere Ferrero, R., Gouttebroze, P., and Kondo, Y. (1983). Astron. Astrophys., 121, 59.

Golub, L., Harnden, F. R., Maxon, C. W., Rosner, R., Vaiana, G. S., Cash, W., and Snow, T. P. (1983). Astrophys. J., 271, 264.

Goraya, P. S., and Singh, M. (1983). Inf. Bull. Var. Stars No. 2455.

Grevesse, N. (1984). Physica Scripta, T8, 49.

Guern, Y., Bideau-Méhu, A., Abjean, R., and Johannin-Gilles, A. (1976). Physica Scripta, 14, 273.

Guthrie, B. N. G. (1981). In Upper Main Sequence CP Stars, 23rd Liège Astrophys. Colloq. (Univ. Liège), p. 189.

Guthrie, B. N. G. (1984), Mon. Not. R. Astr. Soc., 206, 85.

Guthrie, B. N. G., and Napier, W. M. (1980). Nature, 284, 536.

Hack, M. (1981). In Upper Main Sequence CP Stars, 23rd Liège Astrophys. Colloq. (Univ. Liège), p. 79.

Hauck, B., and Slettebak, A. (1983). Astron. Astrophys., 127, 231.

Jacobs, J. M., and Dworetsky, M. M. (1981). In Upper Main Sequence CP Stars, 23rd Liège Astrophys. Colloq. (Univ. Liège), P. 153.

Jacobs, J. M., and Dworetsky, M. M. (1982). Nature, 299, 535.

Klochkova, V. G. (1983). Soob. Sp. Astrofiz. Obs., 37, 73.

Kurucz, R. L. (1979). Astrophys. J. Suppl., 40, 1.

Lambert, D. L., Roby, S. W., and Bell, R.A. (1982). Astrophys. J., 254, 663.

Landstreet, J. D. (1982). Astrophys. J., 258, 639.

Leckrone, D. S. (1980). Highlights of Astronomy, 5, 277.

Leckrone, D. S. (1981). Astrophys. J., 250, 687.

Leckrone, D. S. (1984). Astrophys. J., 286, 725.

Magain, P. (1984). Astron. Astrophys., 134, 189.

Mégessier, C., Michaud, G., and Weiler, E. J. (1980). Astrophys. J., 239, 237.

Mermilliod, J.-C. (1982). Astron. Astrophys., 109, 37.

Mermilliod, J.-C. (1983). Astron. Astrophys., 128, 368.

Michaud, G. (1978). Astrophys. J., 161, 592.

Molaro, P., Morossi, C., Ramella, M., and Franco, M. (1983). Astron. Astrophys., 127, 413.

Mon, M., Hirata, R., and Sadakane, K. (1981). Publs. Astron. Soc. Japan, 33. 413.

Moon, T. T., and Dworetsky, M. M. (1985). Submitted to MNRAS.

Morgan, W. W. (1984). In *The MK Process and Stellar Classification*, ed. R. F. Garrison (David Dunlap Obs., Toronto), p. 18.

Ptitsyn, D. A., and Ryabchikova, T. A. (1986). Paper presented at IAU Coll. 90, Crimea (This volume).

Rakos, K. D., Jenkner, H., and Wood, J. (1981). *Astron. Astrophys. Suppl.*, **43**, 209.

Rice, J. B., and Wehlau, W. H. (1982). *Astron. Astrophys.*, **106**, 7.

Rice, J. B., and Wehlau, W. H. (1984). *Astrophys. J.*, **278**, 721.

Sadakane, K. (1981). *Publs. Astron. Soc. Pacif.*, **93**, 587.

Sadakane, K. (1984). *Publs. Astron. Soc. Pacif.*, **96**, 259.

Sadakane, K., and Jugaku, J. (1981). *Publs. Astron. Soc. Pacif.*, **93**, 60.

Sadakane, K., and Nishimura, M. (1979). *Publs. Astron. Soc. Japan*, **31**, 481.

Sadakane, K., and Nishimura, M. (1981). *Publs. Astron. Soc. Japan*, **33**, 189.

Sadakane, K., Takada, M., and Jugaku, J. (1983). *Astrophys. J.*, **274**, 261.

Smith, M. A., and Parsons, S. B. (1976). *Astrophys. J.*, **205**, 430.

Stickland, D. J., and Weatherby, J. (1984). *Astron. Astrophys. Suppl.*, **57**, 55.

Takada, M., and Jugaku, J. (1981). In *Upper Main Sequence CP Stars*, 23rd Liège Astrophys. Colloq. (Univ. Liège), p. 163.

Welsh, B. Y., Boksenberg, A., Anderson, B., and Towlson, W. A. (1983). *Astron. Astrophys.*, **126**, 335.

Wolff, S. C. and Wolff, R. J. (1976). In *Physics of Ap-Stars*, IAU Colloq. No. 32, ed. W. W. Weiss, H. Jenkner, and H. J. Wood (Universitätssternwarte Vienna), p. 503.