Peculiar Versus Normal Phenomena in A-Type and Related Stars
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THE λ BOO AND RELATED STARS

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ABSTRACT The main properties of this class of rare objects are described, and the criteria selected for discovering new members are indicated. The abundance anomalies, resulting from the scanty analyses made up to now, are discussed together with the theoretical interpretation proposed in the framework of the modified diffusion theory and of the recent selective accretion proposal.
Finally, we discuss the evolutionary stage of the λ Boo stars which, in the HR diagram, lie near, but not on the main sequence.

1. DEFINITION AND CLASSIFICATION PARAMETERS

The definition of the class of peculiar stars known today as λ Boo stars is implicitly contained in the description of the peculiarities of the λ Boo spectrum in the Morgan et al. Atlas of 1943. The first analysis of the λ Boo spectrum by Burbidge and Burbidge in 1956 clearly established a deficiency of the abundances of Mg, Ca, Fe and Sr compared to those of 95 Leo. Another star, 29 Cyg, already detected as being similar to λ Boo on the basis of its spectral classification, was analysed by these authors and found to have similar metal deficiencies. More than 10 years later, Baschek and Searle (1969) carried out a curve of growth abundance analysis of five objects which had been classified as λ Boo by that time. These authors found that only three of them, λ Boo, 29 Cyg and π^1 Ori, form a distinct group from the composition point of view; they also have similar atmospheric parameters, including a low microturbulence velocity. Their chemical composition is characterized by:

- a deficiency by about a factor of 3 in the iron-group elements (Sr, Fe, Ti, Sc);
- a nearly normal abundance of oxygen;
- deficiencies of Mg and Ca compared to Fe.

These authors suggested that such an abundance pattern should define the group of "λ Boo stars".

Then the λ Boo stars were forgotten until the 1980s, when both photometric and spectroscopic researches underwent a revival of interest, but the situation became rather confused, since different candidates were selected by different criteria.

Since the beginning of the space era it has appeared that some peculiarities of the λ Boo spectrum can easily be picked up in the UV range (Cucchiaro et al., 1980).

Baschek et al. (1984) showed that the characteristic features of the λ Boo stars on the low resolution IUE spectra are:

- the two C I lines at 1657 A and 1931 A, which are stronger than in the spectra of normal stars;

- the presence of two broad and unidentified absorption features centered at 1600 A and 3040 A.

Faraggiana et al. (1990) suggested defining the UV properties of the λ Boo stars by the following criteria, easily detectable in the 1200-2000 A range:

- the presence of the broad absorption feature centered at 1600 A;

- the intensity ratio of the C I feature at 1657 A to the Al II 1670 one, much greater than in normal stars of similar temperature.

At the end of the 1980s, following an extensive spectroscopic classification of more than 1000 stars made by Gray and Garrison (1987) in a refined MK system, Gray (1988 and 1991) described in great detail the spectroscopic peculiarities detectable in the visual domain at moderate resolution (67 A mm^{-1}). The purpose was to provide the following, more precise working definition of the λ Boo class:

"*Spectra of these stars are characterized by a weak Mg II 4481 line, a K line type of A0 or slightly later and hydrogen-line type between A0 and F0. For their hydrogen line type, the metallic-line spectrum is weak*".

Moreover, we recall that these stars are distinguished from other weak-lined stars (such as horizontal branch stars) by the fact that their space velocities are those of Population I stars and also that their rotational velocities are moderately high.

From the description of their spectra, it is easy to understand that the selection of members of this class produced ambiguous results for a long time. In the first colloquium on CP stars, Sargent (1967) listed 7 members of what Bidelman indicated as "a somewhat diffuse class"; 4 of these were later rejected. A list of the λ Boo produced by the CDS (Centre de Données Stellaires) in 1982 contained 12 objects; only 7 of them turned out to be real λ Boo stars. The recent catalogue of all possible λ Boo candidates by Renson et al. (1990) has 101 objects, but contains several spurious objects, such as weak-lined F stars and some peculiar objects.

On the basis of the Gray (1988 and 1991) and Faraggiana et al. (1990) papers, we have produced a list of stars, given in Table 1, that fulfill the recently defined requirements; it results from Gray ground observations, to which we added the λ Boo stars detected in the UV range and HD 30422 taken from Gray and Garrison (1989). We consider all these stars good λ Boo candidates on the basis of the fact that all the stars classified as λ Boo by Gray and observed by IUE belong to the same class according to UV criteria, and viceversa not one star among those rejected on the basis of UV criteria appears as λ Boo in Gray's list. In this table, spectral types in parentheses refer to stars not classified by Gray. The UV column indicates stars classified from IUE spectra by us. Δa is a measure of this colour index made by Maitzen and Pavlovski (1989 a, b) as described in Section 2. The last column refers to the search for a signature of circumstellar gas around the stars (see Section 6).

Table 1
The λ Boo Stars

HD	Name/HR	Spectral Type	V sini	(b-y)	UV	Δa	IRAS excess	Circumstellar gas sig.
319	12	A1mA2 Vb	60	0.080	-	-10	—	No detection
4158	-	[A1 III]	-	0.210	UV	-37	—	—
11413	541	A1 Va	125	0.111	UV	-21	—	—
30422	1525	A3 Vb	157	0.101	-	-	—	—
31295	π^1 Ori	A0 Va	120	0.043	UV	-15	probable	No detection
38545	131 Tau	A2 Va$^+$	200	0.042	-	-5	—	—
101108	-	[A3 V]	100	0.115	UV	-13	—	—
105058	-	[A2p]	130	0.129	UV	-17	—	—
107233	-	A1hF0m A1 Va	-	0.070	-	-	—	—
110411	ρ Vir	A0 Va	173	0.040	UV	-17	—	—
111604	4875	[A3 V]	183	0.113	UV	—	—	—
111786	4881	A1.5 Va$^-$	140	0.161	UV	-27	—	Yes
125162	λ Boo	A0 Va	110	0.051	UV	—	Yes	No detection
142703	5930	KA1hF0m A1 Va	-	0.176	-	—	—	—
142994	-	A3 Va	-	0.199	-	—	—	—
183324	35 Aql	A0 Vb	90	0.051	-	-13	—	No detection
192640	29 Cyg	A0.5 Va$^-$	80	0.098	UV	-20	—	—
193256	7764 C	A2 Va	240	0.115	-	—	Yes (mild)	—
193281	7764 A	A3mA2 Vb	90	0.099	-	—	Yes (mild)	—
204041	8203	A1 Vb	70	0.091	-	—	—	No detection
210111	8437	A2hA7m A2 as	60	0.136	-	—	—	No detection
221756	15 And	A1 Va$^+$	110	0.056	-	-10	—	—

The real λ Boo stars appear to be very rare when a systematic survey is made; about 1-2 per cent of the dwarf A-type stars.

2. PHOTOMETRIC PROPERTIES

A correct analysis of photometric properties requires a prior determination of the amount of IS reddening. In our analysis of UV spectra (Faraggiana et al., 1990), we assumed that for stars brighter than 6th magnitude the reddening is not greater than the errors in the measurements. For fainter stars we derived the IS reddening from the intensity of the bump at 2175 A and from the E(B-V) of normal stars situated in the neighbourhood of the programme star. The position of the λ Boo stars in the m_1 vs (b-y) or m_2 vs (B2-V1) diagrams reflects the metal-weak character of these stars. However, their position in these diagrams is not sufficient to distinguish λ Boo from other stars. For example, in the plane m_1, (b-y) (see Figure 1 in Gray, 1991) λ Boo stars occupy a restricted domain where other stars can be found. Reddened B stars, some rapidly rotating A-type stars, some shell stars, some giant and Population II A-type stars are also found there. Therefore, for a further discrimination of λ Boo candidates, Gray (1991) suggested to add the objective-prism luminosity class (usually II or II-III) as a further selective parameter. The remarkably linear distribution of λ Boo in this diagram should be noted, but an explanation for the possible significance of it has not yet been advanced; this is a point that deserves further examination.

More information can be extracted from the photometric behaviour of these stars. For example, a systematic discrepancy has been found between the MK spectral types and those derived from the photometric colour indices (B-V) or (b-y). The blanketing is much lower in the IR so, in order to check if this discrepancy is simply related to the low blanketing of λ Boo stars, a sample of λ Boo candidates, comprising most of the southern hemisphere stars of Table 1, was observed in JHK photometry at ESO in 1990 and 1991, and the preliminary results discussed by Gerbaldi (1991). It turned out that no large discrepancies exist between the spectral types determined by (b-y), (B-V), and (J-K); this indicates that the λ Boo stars do not have any systematic colour excess up to near IR; so the discrepancy between photometric and MK classification becomes a further criterion for a preliminary selection of λ Boo candidates. The too early MK spectral type is related to the criteria used to classify A-type stars, criteria which are partly based on line ratios of elements underabundant in λ Boo stars.

After the discovery of circumstellar matter around Vega, a systematic search for it has been extended to other A-type stars by Sadakane and Nishida (1986) who detected an IR excess on λ Boo and π^1 Ori IRAS data. Recently, Oudmaijer et al. (1992) compiled an extensive list of stars observed by IRAS and showing an IR excess according to new criteria. This latter list contains only the prototype λ Boo, so that an IR excess cannot be ascribed among the general properties of λ Boo stars.

In the domain of narrow band photometry, a helpful colour index may be Δa. Maitzen and Pavlovski (1989 a, b) have shown that Δa photometry, originally designed to detect magnetic peculiar stars, can also be used to discriminate λ Boo candidates; a negative value of Δa indicates a low metal content, but this colour index behaves similarly in some Be stars. Spectroscopic classification of stars selected on the basis of a negative Δa is needed in order to test how powerful this index is, since it could be used as a further indicator for a preliminary selection, in particular when faint stars in clusters of different ages are examined.

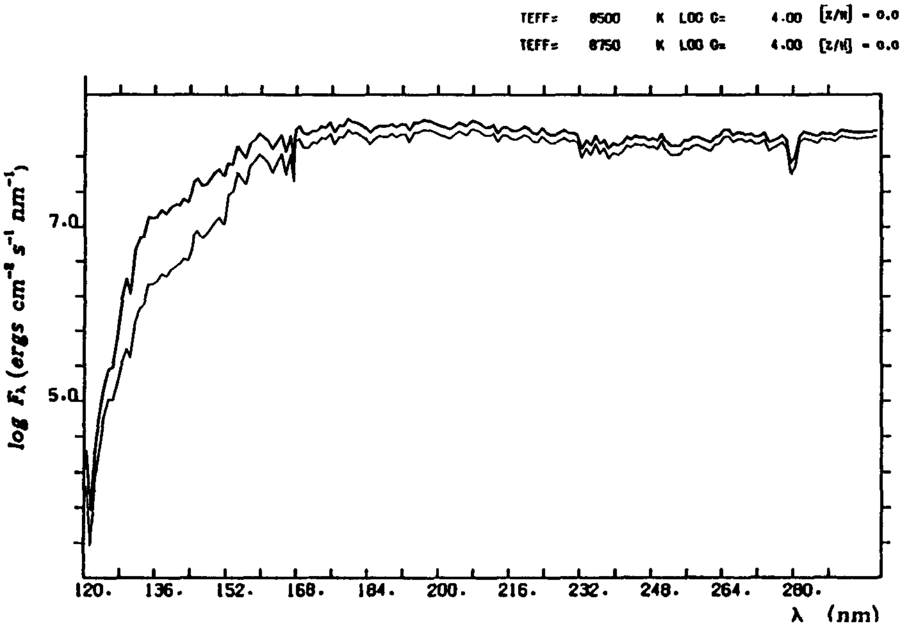

Fig.1 Flux distribution for solar abundances and different T_{eff}.

We also recall that a flux drop in the UV range covered by the short wavelength spectra of IUE is characteristic of A-type stars and, for given values of metal abundances, is directly related to the T_{eff} value. We tested the influence of T_{eff} and metallicity on the flux distribution in the 1200-2000 A range by comparing the appropriate computed fluxes (from the LTE blanketed models of Kurucz, 1991). In the range of T_{eff} covered by the λ Boo stars, a lowering of metallicity by -0.5 dex mimics a rise in temperature of about 250 K; therefore, the UV flux distribution of λ Boo stars cannot be safely used as a temperature indicator, when the comparison is made with "normal" stars; Figures 1 and 2 illustrate this point.

3. ATMOSPHERIC PARAMETERS

Before discussing the observed abundance anomalies and their interpretation, it is worthwhile to stress the difficulties encountered in the study of the chemical composition of these stars. These difficulties regard the determination of:

- T_{eff} and log g;
- metallicities used for the model computation;
- microturbulence velocity;

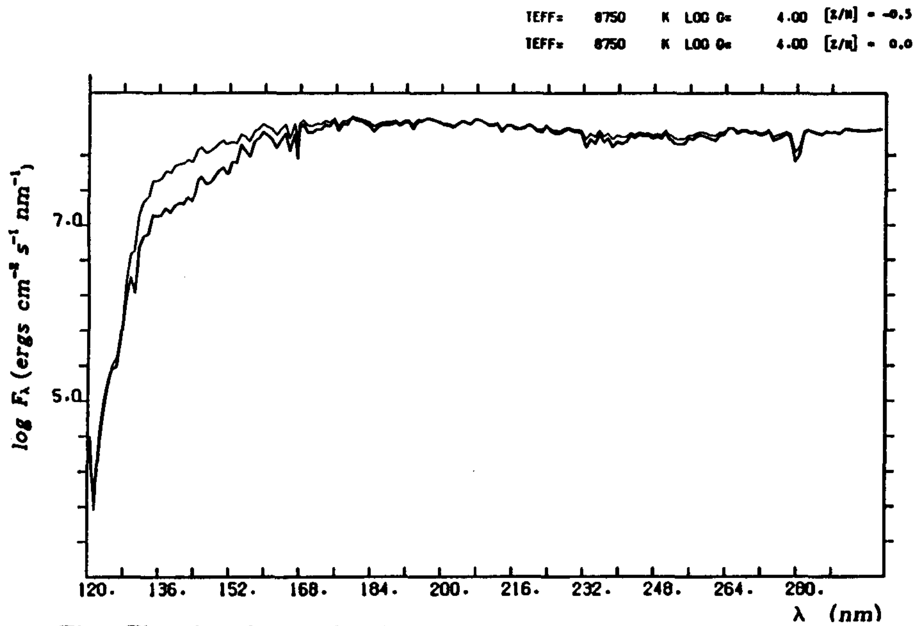

Fig.2 Flux distribution for the same T_{eff}, but different abundances.

- placement of the continuum linked to the v sin$i$ value around 100 km s^{-1}, which characterizes these stars.

As usual, the influence of the adopted oscillator strengths and the effects of LTE departure must also be taken into account.

A preliminary estimate of T_{eff} and log g parameters can be derived from the spectral energy distribution and the photometric colour indices. The new Kurucz (1991) models give a reasonably good agreement with the observations, when lower than solar metal abundances are adopted. The choice of metallicity [Z/H] is important in the UV range, while it has a very small effect on the visual part of the spectrum. As a consequence the (b-y) is not seriously affected by the lower than solar metallicities and may be adopted as a T_{eff} criterion. These points are further discussed by Gerbaldi et al. (1992). We recall that also Baschek and Slettebak (1988) neglected the weak dependence of the (b-y) colour index on the bulk metallicity in their analysis of the UV spectra of λ Boo stars. However, we wish to point out that, CNO abundances being nearly solar, the Kurucz scaled models cannot be taken as "the" good physical approach. In the new version of the ATLAS program the ODF treatement of opacities will be replaced by the sampling method, so that more realistic models can be constructed. A preliminary knowledge of the abundances of some key elements such as Si, Mg, Fe, which are the main ones responsible for the steep flux decrease around 1500 A (Baschek, 1984) will still be necessary for an accurate representation of line blanketing; opacity sampling, in fact, requires enormous quantities of computing time for modeling an atmosphere, compared with the ODF approach. Therefore, the knowledge of metal abundances based on the computing facilities now available will remain fundamental even in the near

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future.

Baschek and Searle (1969) derived the surface gravity from the hydrogen-line profiles and the spectral energy distribution, obtaining log g =4.0 (λ Boo and π^1 Ori) and 3.9 (29 Cyg); for the analysis of UV spectra the constant value of log g = 4.0 was adopted by Baschek and Slettebak (1988) and justified by the fact that λ Boo stars are all located on or near the main sequence. The same constant value was adopted also by Venn and Lambert (1990).

The microturbulence velocity is also an important parameter to know for a correct determination of chemical abundances. Burbidge and Burbidge (1956) adopted the value of 4 km s^{-1} for λ Boo and 29 Cyg; Baschek and Searle (1969) obtained 1.6 km s^{-1} for λ Boo and 4 km s^{-1} for 29 Cyg and π^1 Ori; Baschek and Slettebak (1988) assumed 2 km s^{-1}, as it was not realistic to determine its value from IUE spectra. Venn and Lambert (1990) adopted the mean value of 3 km s^{-1} and noted that the vast majority of the lines they measured were insensitive to the value of this parameter. The same value appears to be the most appropriate one also to Stürenburg (1992, private communication).

As noted by Stürenburg (1991), the main problem in the analysis of the λ Boo stars is their high rotational velocity (we recall that no λ Boo stars are known with v sin$i$ lower than 50 km s^{-1}), which makes it impossible to fix correctly the continuum on the spectra. As a second effect, the high v sin$i$ causes strong blending of spectral lines and prevents the use of equivalent widths for abundance analysis, leaving synthetic spectrum computation as the only correct method for abundance determination.

Magnetic fields were sought for, but not detected in any of the observed λ Boo stars by Bohlender and Landstreet (1990) and Iliev et al. (1990).

4. CHEMICAL COMPOSITION

λ Boo is considered the prototype and the most extreme member of this class as far as its abundances are concerned, but its rôle will be probably superseded by HD 183324 (Holweger and Stürenburg, 1991). The analysis of λ Boo by Baschek and Searle (1969) confirmed the almost normal O abundance already found by Kodaira (1967), and the large Mg and Ca underabundances ($[\epsilon]$=-1) compared to those of Fe and Ti ($[\epsilon]$=-0.5). Smaller underabundances, but with the same pattern, had been already determined by Burbidge and Burbidge (1956). These greater underabundances of Mg and Ca compared to those of Fe and Ti and the slight S underabundance have not be confirmed by the recent analysis by Venn and Lambert (1990); these last authors remark that the origin of this discrepancy has to be mainly attributed to the fact that the equivalent widths of the Fe lines as measured by Baschek and Searle (1969) are larger than theirs. In the three λ Boo stars considered by Venn and Lambert (1990), CNOS have solar or very mild underabundances; other elements are more underabundant, with the highest deficiencies of -2 dex in Mg, Ca and Fe-peak elements in the λ Boo spectrum.

Recent observations of 12 λ Boo stars, chosen among those selected by Gray (1988), are discussed by Holweger and Stürenburg (1991). A large variation in the intensity of the Mg II 4481 line is found; since this line is almost insensitive to T_{eff}, its intensity can be directly related to the Mg abundance. This

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abundance varies between the solar value and an underabundance of -1.7 dex. A similar range in line strength is observed for the Na I resonance doublet, but its translation into abundance effect is not as easy as for the previous line, owing to its dependence on T_{eff} and NLTE effects.

These results are all based on observations in the visual and near IR ranges; the difficulties in deriving accurate abundances are even greater when the UV spectrum is examined, owing to the higher blending of the lines. The only study of the UV spectra is that of Baschek and Slettebak (1988) concerning 9 λ Boo stars, 6 of which belong to our Table 1. This analysis is based on Kurucz' LTE blanketed models and T_{eff} derived from photometric indices. These authors adopted the single value ξ=2 km s^{-1}; a better estimate of the microturbulence parameter would have been unrealistic, since too few lines were available for this determination. However, most of the lines used by them for abundance analysis are strong, so that the abundance uncertainties depend mainly on poor knowledge of the damping parameters. In order to minimize the uncertainties in the derived abundances, only differential analysis has been performed . The almost solar abundances of CNO are confirmed once more, while an underabundance by about -0.5 dex of the Fe-peak elements and slightly higher underabundances of Mg and Al are obtained.

A work in progress by Stürenburg is also dedicated to metal abundances in λ Boo stars; preliminary results (Stürenburg, 1991) obtained by adopting solar log gf and a very low microturbulence (ξ=1 km s^{-1}) are now being revised (private communication); by using recent log gf values and a mean value of 3 km s^{-1} for the microturbulence velocity, the revised abundances would indicate that the average abundance of Mg in a sample of λ Boo stars is not as low as previously estimated.

From the above discussion it is clear that we know roughly the abundance pattern of λ Boo candidates; a detailed abundance analysis based on high S/N observations and made with the synthetic spectrum method over a large wavelength range is highly needed in order to assess the detailed abundance anomalies of these stars.

As a last point on this subject we may mention that, after the assessment of the lower than solar abundances of Vega, this star has been often indicated as a marginal λ Boo star. In fact, many elements appear to be underabundant and, among them, also C (Stürenburg and Holweger, 1990), an element that is not depleted in the atmosphere of λ Boo stars. Further proof that Vega cannot be included among the λ Boo stars is given by its UV spectrum. Since no low resolution IUE spectra of this bright star are available, we looked for the presence of the λ1600 flux depression on high resolution spectra of Vega and λ Boo, degraded to 6 A resolution and kindly made available to us by M. C. Artru. The plots of these two stars clearly indicate the absence of the characteristic λ1600 feature in the Vega spectrum.

In an attempt to look for new λ Boo candidates, we have also extracted from Cayrel et al.'s (1992) Catalogue all the metal-deficient stars in the temperature range covered by λ Boo stars. From the ULDA data base we have extracted the spectra of those observed by IUE for a search of the λ1600 feature, but we have not found any new λ Boo candidates.

Gray (1988) found that the hydrogen line wings may be morphologically distinct from those of normal stars in the same T_{eff} range; 70 per cent of λ Boo stars of his Table show peculiar Balmer profiles: weak core and broad wings. This point is further developed by Iliev and Barzova (1992).

5. INTERPRETATION OF CHEMICAL ABUNDANCES

The diffusion theory, which successfully explains most abundance anomalies of Am and Hg-Mn stars, was first extended qualitatively to λ Boo stars by Michaud et al. (1983). According to them, the λ Boo stars experience a mass loss rate of about 10^{-13} $M_{\odot}$ yr^{-1}, larger than that predicted for Am-Fm stars (10^{-15} to 10^{-14} $M_{\odot}$ yr^{-1}) because the λ Boo stars have a larger rotation velocity. As a consequence, the He convection zone does not disappear as in Am stars and, when deep layers (where diffusion acts downwards) are brought to the surface, underabundances of heavy elements appear. According to the calculations by Michaud and Charland (1986), in the presence of this mass-loss rate, underabundances up to factors 3-5 can develop after 10^{9} yrs. This simple model does not account for the underabundances found by Venn and Lambert (1990) which are higher than the above limit. These authors proposed an alternative interpretation for the λ Boo underabundances based on the similarity between the abundance pattern of these stars and that of the IS gas. They stress the similarities in composition of λ Boo and post-AGB stars. These latter, as well as Vega and λ Boo, exhibit an IR excess attributed to circumstellar dust grains; on the basis of these similarities, Venn and Lambert suggest that the atmospheric composition of a λ Boo star is dominated by selective accretion of the gas present in a circumstellar nebula. The observed depletion of several, but not all elements would be the result of incorporation of the depleted elements into dust grains, which may be expelled later on from the stellar atmosphere. The similarity between the chemical composition of the three λ Boo stars and Vega given in Fig. 4 of Venn and Lambert's paper and that of the IS gas (see for example Fig. 1 in Jenkins (1989)) is striking for most elements. Only the high Na and Mg underabundances of λ Boo stars do not fit this similarity and remain unexplained.

On the basis of this suggestion, Charbonneau (1991) revised the previous diffusion/mass-loss model. He took up the criticism of Baschek and Slettebak (1988) about the effect of diffusion in the presence of meridional circulation induced by the high rotational velocity of these stars, as well as that of Gray (1988) concerning the time scale for the development of surface underabundances. The accretion rate which is required for developing the observed deficiencies in the T_{eff} range of λ Boo stars is 1-2 10^{-13} $M_{\odot}$ yr^{-1}. The agreement found between observations and this simple diffusion/accretion model justifies the further detailed calculations currently in progress by the same author.

Several tests of the validity of the diffusion/mass-loss and of the diffusion/accretion models have been proposed by Venn and Lambert (1990) and by Charbonneau (1991 and 1992 b); among them we focus our attention on the abundance of Zn. This element should be depleted like the other Fe-peak elements if diffusion is the main process acting in the atmosphere of λ Boo stars; on the contrary, if accretion of gas is the dominant process, Zn, as in the interstellar gas, should share the abundance of light elements because of its low condensation temperature. We have performed a preliminary test by looking at the two strongest lines of Zn II in the UV spectrum of λ Boo. The computation of synthetic spectra around these wavelengths shows that λ2025.483 is badly blended with other three lines almost equally strong, Cr II 2025.616, Co II 2025.754 and Mg I 2025.824. The other line, λ2062.004, is severely blended *only* with Cr II 2061.575 whose abundance is probably depleted by more than a factor of 10; a synthetic spectrum computed with T_{eff}=8750 K, log g=4. and [Z/H]=-1 has been produced. With a further correction of CNOS abundances, taken as solar, and of the Fe underabundance increased to -2 dex, we obtained the result plotted in Figure 3. The inspection of this figure suggests that the Zn abundance is not far from solar, but clearly a further detailed analysis of the whole spectrum and the establishment of the general abundance pattern is required before assessing the value of the Zn abundance.

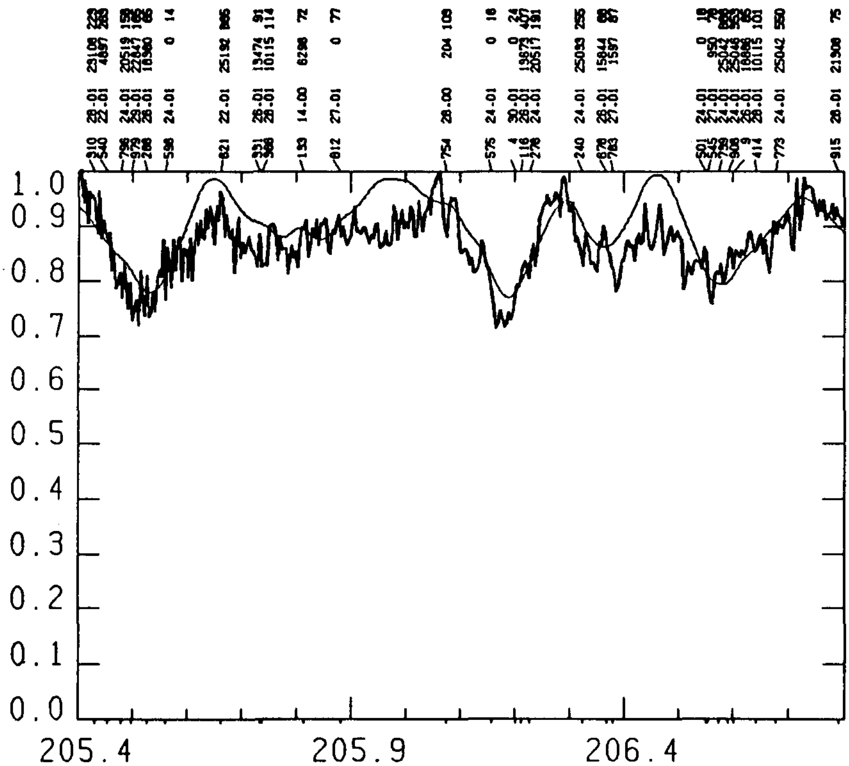

Fig.3 The Zn II 2062.004 region of λ Boo (thick line) overlapped on a computed spectrum (thin line).

As a further test of the limitations of the diffusion/mass-loss model, the effect of meridional circulation on particle transport was studied for the two elements Ti and Ca by Charbonneau (1992 b); he found that surface underabundances do not develop in rotating models.

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Holweger (1991), in his analysis of abundance anomalies among A-type stars, showed the anticorrelation between C and Si abundances. The extension of this study to λ Boo stars (Holweger and Stürenburg, 1992) reinforces the hypothesis of separation of gas and dust in the IS material around these stars, followed by accretion of the gas, but not of the dust. A continuous sequence from preferential gas accretion in the λ Boo stars to the preferential dust accretion in Am stars is the obvious explanation for the relations given in these two papers. The study and the interpretation of the λ Boo chemical abundances thus become a piece of the large puzzle concerning the atmosphere of A-type stars in general.

6. THE EVOLUTIONARY STAGE

It has been shown that the pure diffusion/mass-loss mechanism seems not to be sufficient to explain the chemical anomalies of λ Boo stars, owing to their high rotational velocity (Charbonneau, 1992 b). The only alternative so far proposed is accretion; it appears to explain the main abundance peculiarities of these stars. But it leaves one question open: the accretion of gas presupposes that some gas, already enriched in low temperature condensates, is close to the star. If this were simply the general IS matter present in the Galaxy, the λ Boo phenomenon would be much more common than is observed. It is also unlikely that the process envisaged by Bond (1991), of photospheric origin of the dust and its removal by radiation pressure, occurs also in λ Boo as in post-AGB stars. Therefore, we have to consider at what stage of stellar evolution a star is surrounded by circumstellar matter.

Some peculiar post-AGB stars, stars on the way to becoming planetary nebulae, show noticeable similarities to λ Boo stars. These peculiar objects have a T_{eff} similar to that of λ Boo stars, but a much lower gravity, as demonstrated by their Balmer line profiles and as expected from their evolutionary stage. An IR excess, as in λ Boo and perhaps in π^1 Ori, has been detected by IRAS in some post-AGB stars and interpreted as being due to hot dust. This dust originates from recent mass loss, the rates of which have been estimated to be of the order on 10^{-8}-10^{-7} $M_\odot$ yr^{-1} (Trams et al. 1989). The similarity in abundance anomalies between these two classes of stars lies behind the hypothesis of selective accretion as a similar mechanism acting on both classes of stars (Venn and Lambert, 1990). A further similarity with post-AGB stars is the existence of stars either with no IR excess (BD +39 4926) and with high IR luminosity (HD 44179).

The most plausible explanation has been suggested by Waters et al. (1992): the separation of gas and dust occurred in a disc which, in λ Boo stars, is the remnant of that from which the star formed, while in the peculiar post-AGB stars it is a circum-system disc formed while the star was still on the AGB. The presence of the disc gives rise to shell lines only when the stars are viewed edge-on; this could be the case of HD 111786, the only λ Boo star in our Table 1 (among the seven for which this search has been made) showing sharp narrow components of several lines. In its spectrum narrow absorption components are overlapped on the broad photosphere, not only on the Ca II K line as already pointed out by Gray (1988), but also on the Na D doublet, as noticed by Holweger and Stürenburg (1991). These features are interpreted in both papers as a signature of circumstellar material. Similar absorption cores are clearly present on UV spectra. Figure 4 gives, as an example, the region around the two Fe II lines at λ2585.876 and λ2599.396 starting from the ground level. The presence of these circumstellar components makes the spectrum of HD 111786 similar to that of β Pic, the best candidate for a star surrounded by a proto-planetary disk. Its metal deficiency and the v sini=139 km s^{-1} are other similarities with λ Boo stars. For β Pic, too, the most recent hypothesis is that of a very young dwarf, with an age of about 10^8, which has not yet reached the ZAMS (Paresce, 1991). The links between λ Boo and β Pic and with Vega-like stars suggest a common mechanism acting on them.

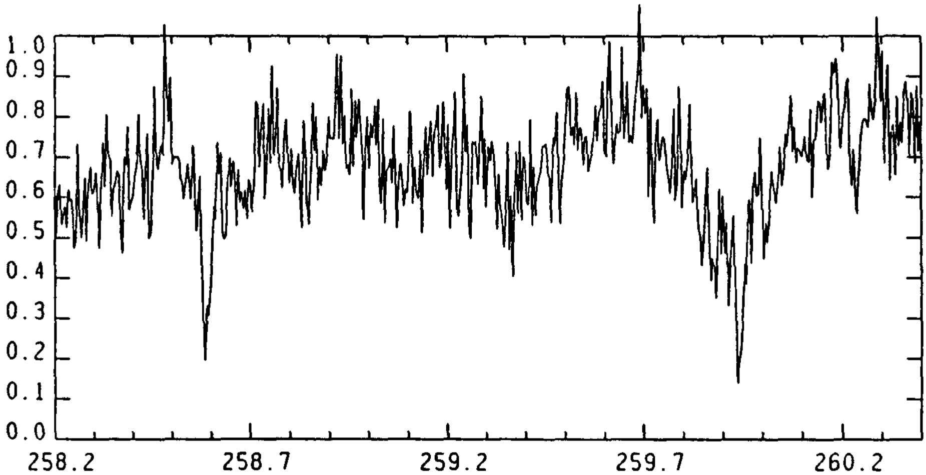

Fig. 4 The region of Fe II 2585.876 and Fe II 2599.396 in the spectrum of HD 111786 (HR 4881).

The mechanism of gas, but not dust accretion proposed by Waters et al. (1992) should take place during the late phases of the pre-main sequence evolution and should stop when the star, approaching the ZAMS, is surrounded by a disc containing too low an amount of material. For some λ Boo and Mg-weak stars, Gerbaldi et al. (1992) derived the bolometric luminosity $L/L_\odot$, placing them on the HR diagram together with tracks for pre-main and post-main sequence evolution. λ Boo and 29 Cyg have lower v sin*i* and are nearer the ZAMS than π^1 Ori and ρ Vir. According to the UV criteria adopted by Faraggiana et al. (1990), λ Boo and 29 Cyg have a more pronounced λ Boo character. In fact, the measures of λ1600 and of the ratio C I 1657/Al II 1670 are 38 mA, 5.65 for λ Boo and 41 mA, 4.95 for 29 Cyg, while the same quantities are 26 mA, 4.55 for π^1 Ori and 14 mA, 4.25 for ρ Vir. The inspection of Figure 3 in Stürenburg (1991) shows also that 29 Cyg has larger underabundances than π^1 Ori; the same trend of the abundance pattern appears from the inspection of Table 4 in Venn and Lambert's (1990) paper and concerns λ Boo, 29 Cyg and π^1 Ori. If we take seriously a trend in abundance anomalies coming from so limited a sample, it follows that the highest peculiarities are observed in stars nearest the ZAMS.

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The diffusion/mass-loss model predicts that 19^9 years are necessary for underabundances by factors of 2-5 to materialize so that the highest underabundances should be observable in stars near to the end of main sequence life, contrary to what we have just shown.

Moreover, no λ Boo star should exist in young clusters. On the contrary, in order for there to be selective accretion of clear gas by the stellar photosphere, it is necessary that some material, gas and dust, should surround the star. If we accept the scenario proposed by Waters et al. (1992), the accretion on the surface of a λ Boo star occurs just before the star arrives on the ZAMS, and it becomes obvious that the highest anomalies are found in the objects nearest the ZAMS. The very low number of λ Boo stars may indicate that mixing due to meridional circulation works rapidly and efficiently and the λ Boo phase of stellar life is quite short.

Detailed calculations are needed to prove this hypothesis, which, if true, would give us the opportunity to study the hot analogues of T Tau stars or the cool analogues of Herbig Ae/Be stars, an, as yet, not fully explored phase of life of intermediate mass stars.

From the observational point of view, it becomes of fundamental importance to set upper and lower limits to the ages of λ Boo stars. The presence of two λ Boo stars as secondaries in young binary systems (Abt and Cardona, 1983) and the clear example of a λ Boo star, HDE 290799, detected by Gray and Corbally (1992) in the Orion OB1 association are in favour of the scenario we have presented.

However, there are other observations which seem to contradict it. Tentative identifications of the two stars SS 202 11 and 1 HLF 5 10 as candidates of evolved λ Boo stars have been made by Corbally and Gray (1991). Another suspected old λ Boo object is the secondary of the eclipsing system τ Per (Griffin et al., 1992). In their study of field horizontal-branch stars at high galactic latitude, Corbally and Gray (1992) detected 10 λ Boo candidates at distances from the galactic plane of up to 4.5 kpc, but for most of them the membership to this class is not effectively proved.

To conclude we recall that Charbonneau (1992 a) used the study of the λ Boo phenomenon as a significant example to illustrate the need for interplay between numerical and observational work in solving a problem. We hope that the availability of *"1) flexible numerical schemes and associated codes 2) powerful computers and 3) high quality observations"* will make these strange objects better understood at the next meeting and that some of the following questions will have found the answer.

Is the low percentage of λ Boo stars the result of a short-lived phase of stellar evolution? At what epoch of star formation/evolution did the accretion take place? Why does a direct relation between IR excess and λ Boo character, a signature of gas accretion, seem not to exist? How long does an A-type star keep its abundance anomalies before superficial layers are homogeneized? Is there a relation between the abundance diversity of stars belonging to the same class (e.g. λ Boo stars) and their evolutionary stage?

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DISCUSSION (Gerbaldi and Faraggiana)

GRIFFIN: You mentioned that one criterion of a λ Boo star is that the Ca II K-line is very similar to that of a normal A0V star. Now, the title of this meeting is "Peculiar versus Normal Phenomena..." and the score at half-time is a complete walkover for the peculiar phenomena because the normal phenomena seem to have defaulted. Even the archetypal A0 V star Vega, which represents the basis of classification of A V stars, has been disqualified, but I'm not sure that the classification of all the other A dwarfs has been adjusted accordingly. The value of the K-line criterion may therefore be questionable.
GERBALDI: Yes, that is right, but the K-line criterion allows us to intercompare the classification results.
GRIFFIN: In the wide binary τ Per (G8 III + "A2 V"), the secondary star has been shown to have a spectrum that closely resembles that of λ Boo. How would such a discovery affect your resolution of the question regarding the evolutionary status of the λ Boo stars?
GERBALDI: Before drawing any conclusion we must be sure that the "A2 V" of this system is a "real λ Boo" star, according to the criteria we gave. So, UV observations are needed.
TAKADA-HIDAI: Are there any correlations between the degree of underabundance of some species and the strength of the UV flux depressions near 1600 Å and 3050 Å among λ Boo stars?
GERBALDI: The sample of λ Boo stars analysed is very small. We have just noted the trend, that the larger the depletion in [Fe/H], the stronger is the depression at 1600 Å.
SHYLAJA: The IR excess has been detected only in one case, so can it be taken as a general property of the λ Boo stars? And have sources other than circumstellar dust been considered?
GERBALDI: The sample is much too small to be taken as representative of the λ Boo class and to draw any general conclusion. The sensitivity of the *IRAS* detectors must be taken into account. The excesses observed have been interpreted in terms of black body radiation.