PARTICLE TRANSPORT IN NON-MAGNETIC STARS

G. Michaud
Département de Physique
Université de Montréal
C.P. 6128, Succ. A, Montréal
CANADA H3C 3J7

ABSTRACT. The observations of AmFm, λ Booti, HgMn and He rich stars that are explained without any arbitrary parameter by diffusion are briefly reviewed, followed by those observations that are not explained by this simple model. Mass loss is then shown to explain a large fraction of the observations that are not explained in the parameter free model. It seems to play a role in the λ Booti, AmFm, He rich and the hot horizontal branch stars. It is only of about 10^{-15} to 10^{-13} $M_\odot$/yr. Abundance anomalies then help to determine stellar hydrodynamics. It is finally suggested that recent observations of Li underabundances in F stars of the Hyades represent an extension of the AmFm star phenomenon.

1. THE PARAMETER FREE MODEL

Diffusion is a basic physical process and plays a role everywhere a more efficient transport process does not wipe out its effects. If one assumes that a star arrives on the main sequence with the convection zones as given by standard evolutionary models and one allows the chemical separation to go on unimpeded, one obtains what I call the parameter free model for the non magnetic stars. It is a simply defined stellar model that, as we shall see, leads to large abundance anomalies, indeed larger than observed in the peculiar stars considered here.

As an A or B star arrives on the main sequence it has a He II convection zone that extends roughly down to T = 50 000 K. It is joined by overshooting to the superficial hydrogen convection zone (Latour, Toomre and Zahn 1981) if the star is cool enough to have one (T_{eff} < 10 000 K). Diffusion then goes on directly below the He II convection zone (see Fig.1a). Helium settles gravitationnally since the radiative acceleration on it is smaller than gravity (Michaud et al. 1979). At the same time the heavy elements either diffuse into or out of the convection zone depending on wether the radiative acceleration is larger or smaller than gravity. Once the helium abundance has been reduced by a factor of about 3, the helium convection zone disappears (Vauclair, Vauclair and Pamjatnikh 1974). The chemical separation then starts occuring (see Fig. 1b) below the hydrogen convection zone if the star

C. R. Cowley et al (eds.), Upper Main Sequence Stars with Anomalous Abundances, 459–472.

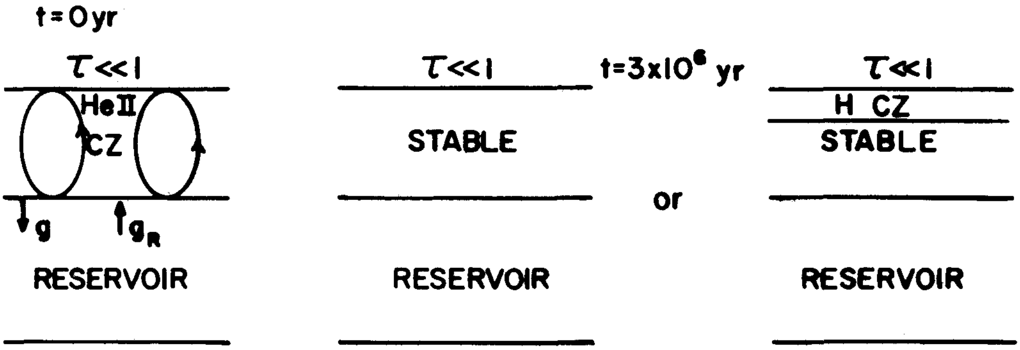

Figure 1. In the effective temperature range considered, stars form with a superficial He convection zone. When the He abundance has been sufficiently reduced it disappears and there remains a superficial H convection zone only if the star is cooler than 10 000 K.

has one or in the atmospere itself if the star does not have one. The starting conditions for the evolution of the abundances in that phase are those left over by the separation that occured below the He convection zone.

As I have already discussed in Liège (Michaud 1981), this very simple model, which is the only one that can be described without arbitrary parameters, is known to make assumptions that are not always valid. Additional phenomena are believed to be important in stellar interiors and, because of our ignorance of stellar hydrodynamics, they cannot all be described without arbitrary parameters. In Liège I have already discussed the potential effects of meridional circulation, of the tidal effects of a companion and of horizontal instabilities that could lead to horizontal inhomogeneities. In the review I made in Montréal (Michaud 1980), I have described the possible effects an inverted μ gradient may have in causing vertical inhomogeneities in stratified regions. Turbulence, accretion, a corona, mass loss are all effects that are potentially important but that we have to use arbitrary parameters to represent. Even if the HgMn and AmFm stars have no observational magnetic fields, a magnetic field below the observational limit may still have important effects on chemical separation.

We however adopt the methodological point of view that, while such phenomena may be important, one should first try to explain as many observations as possible without the use of any arbitrary parameter. Only because the parameter free model will be shown to explain a large fraction of the observations shall we investigate the possible complications. The importance of a given hydrodynamical process will be considered established only if one proces that can be described by, say, one arbitrary parameter can explain a substantial fraction of the observational facts the parameter free model does not explain. Mass loss will be seen below to be such a process.

More complete lists of references may be found in Vauclair and

Vauclair (1982) and Alecian and Vauclair (1983).

2. PHENOMENA EXPLAINED BY THE PARAMETER FREE MODEL

I here very briefly describe phenomena that are explained in a natural way by the parameter free model. References will be given to papers where a more complete description can be found.

1) The peculiarities appear in those stars that are likely to have the most stable atmospheres (Michaud 1970) so where the effects of diffusion are least likely to be wiped out by mass motion. They are slow rotators, are at an effective temperature where convection zones are either absent or very shallow and where mass loss is small, and have magnetic fields that may well stabilize the outer atmosphere.

2) The HgMn stars occur at T_{eff} > 10 000 K while the AmFm stars occur below. In the HgMn stars the separation then goes on in the atmosphere itself whereas it must go on below the hydrogen convection zone in the AmFm stars. This leads to the observed qualitative difference between the abundance anomalies of the two groups of stars (Michaud et al. 1976).

3) That the number of anomalous abundances be much larger on the magnetic than on the non magnetic stars is explained by the magnetic field making it impossible for the elements to leave the atmosphere where it is horizontal. An atomic species can become overabundant even if its radiative acceleration would push it into the interstellar medium since it is stopped by the horizontal magnetic field when it is ionized (Michaud, Mégessier and Charland 1981).

4)The observed near exclusion of the AmFm and the Delta-Scuti phenomena. If the abundance anomalies are caused by diffusion, helium has settled below the convection zone in the AmFm stars so that the driving mechanism of the pulsations has disappeared in the AmFm stars (Kurtz 1976, Baglin 1972, Michaud 1980).

5)The model correctly predicts which elements can be supported by radiation pressure and be overabundant and which elements are not supported and are underabundant. The maximum observed anomalies can further be explained by the migration of the elements from the envelope to the surface. The envelope of the anomalies is thus explained without arbitrary parameters (Michaud 1970, Watson 1971, Michaud et al. 1976 and Fig.4 of Michaud 1976).

6)Using the recent results of Tassoul and Tassoul (1982 and the following serie of papers) it can be shown that the anomalies appear in those stars rotating slowly enough for the meridional circulation velocity to be small enough for the chemical separation to go on unimpeded. This is true for both the HgMn stars (Michaud 1982) and the AmFm stars (Michaud, Tarasick, Charland and Pelletier 1983). In the latter case the tidal effects of the companion were also taken into account.

7)For the HgMn stars, detailed radiative calculations (mostly NLTE) have been carried in the atmosphere for He, Be, B, Mg, Si, Ca, Mn, Sr and Ba. In nearly all cases they reproduce, without arbitrary parameters, the envelope of the observed abundance anomalies (Michaud et al. 1981, Borsenberger, Michaud and Praderie 1979, 1981a, 1984, Alecian and Michaud 1981, Alecian and Vauclair 1981). These calculations were undertaken in order to allow a precise comparison of the predictions of the parameter free model with observations. Some problems have arisen. They constitute the facts that point to the need for additional hydrodynamic processes.

3. OBSERVATIONS THAT CONTRADICT THE PARAMETER FREE MODEL

There are a number of observations that cannot be explained by the parameter free model. I here list only those that appear best established.

1)It has long been clear to workers in the field that the large variations in the anomalies observed from star to star could not all be explained by the parameter free model. Some are explained by T_{eff} and log g differences. But this does not seem to be enough. It has been suggested at this conference that rotation may be an additional important parameter (see the evidence presented by Boyarchuck and the results of Didelon presented by Mégessier). An additional parameter (other than T_{eff} and log g) has to be involved and it might be related to rotation.

2)The observed overabundances in the AmFm stars are by factors of about 10 whereas diffusion would easily lead to overabundances by factors of 10^3 (Michaud et al 1976). The attempt to explain these lower abundances by turbulence has not been very successful (Vauclair, Vauclair and Michaud 1978) mainly because a small amount of turbulence wipes out the Ca and Sc underabundances without affecting significantly the overabundances of the heavy elements.

3)The existence, at the same temperature as the AmFm stars, of a group of stars that have underabundances of heavy elements, the λ Booti stars (Cowley et al. 1982). Their existence has been emphasized at this meeting.

4)The existence of the helium rich stars. Explanations in terms of diffusion based models have been suggested. However in the parameter free model, helium, not being supported by radiation pressure (Michaud et al. 1979), is underabundant. Only models involving mass loss and/or magnetic fields can lead to overabundances of He.

5)The existence of boron in some of the HgMn stars. According to the results of Borsenberger et al. (1979), boron is not only supported by radiation pressure in the atmosphere but is also pushed into the interstellar matter, so that no overabundance is expected to accumulate in the line forming region. Boron is however observed in a large fraction of the HgMn stars (Leckrone 1981, Sadakane and Jugaku 1981).

6)Even though the observed overabundance of Be is supported by the radiation pressure in the atmospheres of the HgMn stars and Be remains bound to the star (it is not pushed into the interstellar matter) it however accumulates higher than the line forming region unless some turbulence is present. The strength of its lines is not explained by the parameter free model even though the observed abundance is (Borsenberger et al. 1984, Borsenberger et al. 1981b).

4. ABUNDANCE ANOMALIES AND MASS LOSS

In my opinion the parameter free model explains a sufficient fraction of the observations for us to conclude that diffusion is the basic process responsible for the abundance anomalies. A model explaining the remaining facts would probably involve some of the hydrodynamical processes that I mentioned in Section 1. Whether it is possible to gain information on the hydrodynamical processes from abundance anomalies will depend on the number of observed facts that a simple and plausible phenomenon explains. Only if many observations are explained by a phenomenon parametrized by one arbitrary parameter should we accept that it plays a significant role in stars. Even if it were not possible to establish beyond reasonable doubt the importance of a given phenomenon however, merely knowing the potential effects of a plausible hydrodynamical process on abundance anomalies is interesting. Here I will restrict myself to a study of the potential effects of mass loss on abundance anomalies. How large does a mass loss need to be before it affects the anomalies? Does it need to be larger than in the OB stars or than in the Sun? It is clear that stellar atmospheres cannot be in hydrostatic equilibrium to infinity; the outer boundary condition must somewhere include dynamic processes. Here we assume that at the boundary there is homogeneous mass loss, that is the wind leaves with the chemical composition of matter at the top of the atmosphere. The wind is then parametrized by a single parameter, the mass loss rate.

The mass loss rate leads to a generalized outward flow of matter:

$$\frac{dM}{dt} = -4\pi R^2 N_H m_p v_w \qquad (1)$$

I assume that the mass loss rate does not substantially modify the stellar structure. This is justified for mass loss rates of 10^{-14} solar masses per year lasting 10^9 years, since only a very small fraction of the mass is involved. The conservation equation may then be written:

$$\nabla (c\, N_H(v_w + v_D)) = 0 \qquad (2)$$

where the diffusion velocity is given by its usual expression:

$$v_D = -D_{12} \left[\frac{\partial \ln c}{\partial r} + (g - g_R) \frac{m_p}{kT} - k_T \frac{\partial \ln T}{\partial r} \right] \qquad (3)$$

Calculations have been carried out for the AmFm stars, the λ Booti stars, the He rich stars and hot horizontal branch stars.

4.1 The AmFm Stars

The paramater free model for the AmFm stars already explains which elements are overabundant and which are underabundant as the result of the competition between the radiative and gravitational accelarations at the bottom of the hydrogen convection zone (Michaud et al. 1976). It also explains the binary period range, or equatorial rotation velocity range, over which the phenomenon is observed (Michaud et al. 1983). The predicted overabundances are however larger than observed (see Fig 3a of Michaud et al. 1983). Turbulence appears to be ruled out as the main cause of the reduction of the overabundances because, if it is strong enough to decrease sufficiently the overabundances of the heavy elements, it completely wipes out the underabundances of Ca and Sc (Vauclair et al. 1978).

Consider the effect of a small mass loss rate, say 10^{-15} $M_{\odot}$/y. As can be seen from Fig. 4 of Michaud et al. (1983), such a mass loss rate does not affect the underabundance of Ca. Similar calculations would similarly show that it does not affect those of Sc either. As can be seen from Fig. 3 of the same paper it however reduces the overabundance factor of, say, Eu from 1000 to 10. The exact overabundance factor becomes time dependant. The observed overabundances usually do not exceed factors of about 10 in AmFm stars (Preston 1974). A comparison with observations shows that the iron peak and the heavy elements are affected in a consistent manner. The observations then suggest the existence of mass loss rates of about 10^{-15} $M_{\odot}$/yr in AmFm stars. If the mass loss rate were larger by a factor of more than ten, the overabundances would be reduced sufficiently that this star would not be classified AmFm any more. If it were smaller by more than a factor of ten the overabundances would be larger than observed.

To understand the physical effects of mass loss in other objects to be discussed below, it is useful to understand how the mass loss modifies the separation. Consider where the separation occurs in the particularly simple case of helium (see Fig 1b of Michaud et al. 1983). The profile of the helium abundance is shown at the moment the helium abundance has been reduced sufficiently in the convection zone for the He convection zone to disappear. For a mass loss rate of 10^{-13} $M_{\odot}$/yr the separation occurs mainly at a depth where there is 10^{-5} of the stellar mass above. It occurs two orders of magnitude in mass closer to the surface if the mass loss rate is smaller by a factor of ten. It then occurs within a factor of ten of the bottom of the convection zone. This can be understood by calculating the diffusion flux as a function of depth. The diffusion flux of a given element is proportional to the product of the diffusion velocity by the density. Since the gravitational settling diffusion velocity is inversely proportional to density but directly proportional to $T^{1.5}$, the diffusion flux ends up increasing with depth as the temperature increases. Even if the diffusion flux is smaller than the mass loss flux just below the convection zone, it can still be larger than the mass loss flux deeper in the star. This happens in the cases considered here. Helium becomes underabundant in the atmosphere when arrives at the surface, the mass that was at the depth where the He separation flux was larger than the mass loss flux as the star formed. For the larger mass loss rate considered, this happens after 10^{9} years. In the presence of mass loss, the separation can so occur only where the diffusion flux is larger than the mass loss flux and this happens deeper as the mass loss rate is increased. In what follows, other examples of this competition between mass loss rate and diffusion fluxes will be presented.

4.2 The λ Booti Stars.

The effect of increasing the mass loss rate is most dramatically emphasized by our recent calculations for the λ Booti stars. These are found at about the same effective temperature as the AmFm stars and are on or close to the main sequence (Hauck and Sletteback 1983). Instead of overabundances of heavy elements, they show underabundances of most heavy elements by factors of about three (Baschek and Searle 1969). Even if the details of the anomalies may not be so well known, there seems to be little doubt that there exists stars that have underabundances of heavy elements at the same temperature as the Am stars have overabundances. The success of diffusion based models in explaining the overabundances seems to have led to a non-status for the λ Booti stars as noted by Cowley et al. (1982).

To understand how it is possible for diffusion to lead to underabundances of heavy elements it is first necessary to realize how the radiative acceleration on heavy elements varies with depth in stellar atmospheres. In Fig. 2 is shown the radiative acceleration on Cr as a function of the mass above the point of interest. In this model log $g = 4$, so that the radiative acceleration on Cr is clearly larger than gravity close to the convection zone but becomes equal to or smaller than gravity at a depth of about 10^{-3} of the total mass. If one adds the downward contribution of thermal diffusion the diffusion velocity is certainly downward there. From Fig. 2 of Michaud et al. (1983) one sees that a similar behavior occurs for most heavy elements. There is then a point in the star where the diffusion is downward when the star arrives on the main sequence. In the absence of mass loss this will lead to local underabundances of elements. If the mass loss rate is sufficient, the mass loss will expose these regions to view within the life of the star. Underabundances will be large if the mass loss rate flux sufficient to expose the matter is smaller than the diffusion flux as defined above for He in the case of the AmFm stars (see section 4.2).

Examples of results of detailed calculations are shown on Fig. 3 for Cr and Ti. For a mass loss rate of 10^{-13} $M_{\odot}$/yr, Cr becomes underabundant after about 10^{8} years and remains underabundant for the rest of the life of the star. <u>If</u> the mass loss rate is 3 times smaller, Cr remains mainly overabundant. <u>If</u> the mass loss rate is ten times larger, the underabundances that appear on the surface within the stellar life time are of only 25%. There is then only a factor of about 3 around the optimum mass loss rate that allows underabundances of the size observed to materialize. Very similar results are also shown for Ti. The early overabundances are caused by the arrival on the surface of matter that was originally where diffusion was upwards.

In Table 1 are shown the underabundance factors that a mass loss rate of 10^{-13} $M_{\odot}$/yr leads to in a star with an effective temperature of 7800 K and log $g = 4.4$. These are of the same order as those observed in λ Booti stars. Even though no effort was made to maximize the underabundance factors obtained, we have conducted calculations for different values of the mass loss rate, temperature and gravity so

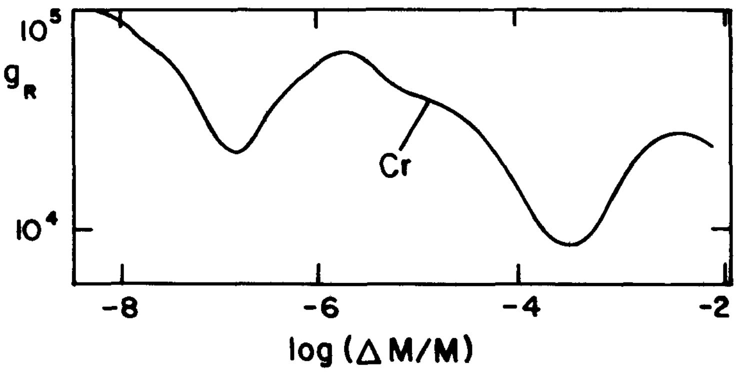

Figure 2. Radiative acceleration on Cr as a function of the mass above the point of interest.

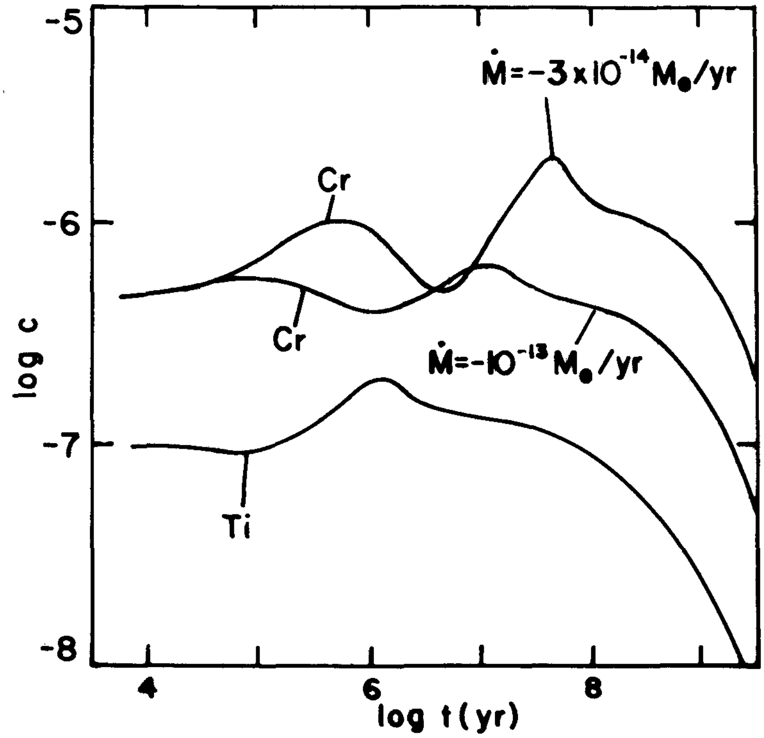

Figure 3. Time evolution of the abundance of Cr and of Ti. A solar abundance is assumed when the star formed.

that we can say that the underabundance factors cannot be much larger than those indicated. For a few individual elements they could be somewhat larger but they could not be systematically much larger than indicated (see Michaud and Charland, in preparation, for details). For instance, diffusion with mass loss could not explain generalized underabundances by factors of 100, in stars with lifetimes of 3 10^9 years and less.

TABLE 1
Underabundance Factors after 10^9 Years

Element	Abundance factor	Element	Abundance factor
C	0.41	Ti	0.24
Si	0.61	Cr	0.40
Ca	0.26	Mn	0.48

4.3 The He Rich Stars

As briefly mentioned above, He is not supported by radiation pressure even in the early main sequence stars where it is observed to be overabundant (Michaud et al. 1979). In the absence of mass loss diffusion then leads to underabundances of He in the non-magnetic stars.

Vauclair (1975) has suggested that, if the mass loss rate is appropriate, it could lead to overabundances of helium in the atmospheres of the relatively hot stars observed to have such anomalies (Osmer and Peterson 1974). If the mass loss rate is appropriate, hydrogen will drag helium along and He will accumulate where the dragging is least effective that is where He is most in the form of neutral helium, since the diffusion coefficient is then some two orders of magnitude larger than when it is ionized. In the stars where it is observed to be overabundant, helium is least ionized in the atmosphere, so that is where it accumulates. This model is the only one based on diffusion and able to explain overabundances of He in the non-magnetic stars.

This model implicitly assumes that the helium flux continues to arrive in the atmosphere for the whole life of the star. This might not be the case if the mass loss rate were slow enough that the separation could be effective in the envelope, just as described above for the AmFm stars. We have (Michaud and Dupuis in preparation) evaluated how long it takes for the helium abundance to be reduced by a factor of three in the flux arriving in the atmosphere. It takes 1.5 10^9 years if the mass loss rate is 10^{-12} $M_\odot$/yr, a mass loss rate about equal to that needed to lead to the He overabundance. This is longer than the expected life time of those stars. This is then consistent with the assumptions of the model of Vauclair (1975) for the overabundance of He.

4.4 The Si Underabundance in the B and O Subdwarfs.

It has been revealed by IUE observations of O and B subdwarfs that they have underabundances of silicon by 4 or 5 orders of magnitude while having about normal N, underabundant C and ten times underabundant

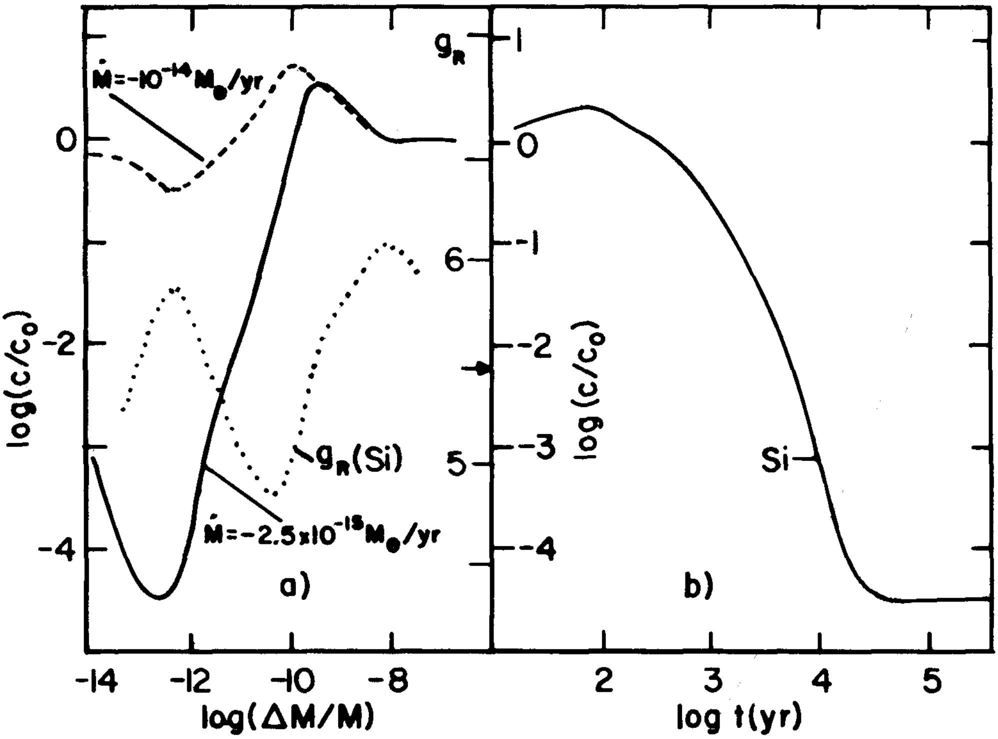

Figure 4. On part a) are shown the radiative acceleration (center scale) as a function of the mass above the point of interest, as well as profiles of the Si abundance (left hand scale) also as a function of depth. The time evolution of the Si abundance is shown on part b). Gravity is indicated by an horizontal arrow on the central scale.

helium. The C abundance varies considerably from star to star (Baschek et al. 1982, Heber et al. 1984, Lamontagne et al. 1985). These subdwarfs have log g = 5.5 and effective temperatures between 30 000 and 40 000 K. Their evolutionary status is not well known.

Explaining such objects by models based on nuclear physics seems extremely difficult: it is difficult to destroy helium by nuclear reactions (Vauclair and Reeves 1972) and probably impossible to destroy Si by such a large factor while not destroying N. Ever since the He underabundance was measured, diffusion was called upon to explain it. We here show how diffusion can also explain the Si underabundance but only if mass loss is also present.

In Fig. 4a is shown the radiative acceleration on Si in the envelope of a star with T_{eff} = 35 000 K and log g = 5.5, as is appropriate for the sdOs and sdBs. The radiative acceleration has a maximum in the atmosphere, where Si is supported by the radiative acceleration for a solar Si abundance (the radiative acceleration is larger than gravity). In the absence of mass loss diffusion is not expected to lead to underabundances of Si in the region where the lines form, contrary to the suggestion of Baschek et al. (1982) and of Heber et al. (1984). The radiative acceleration becomes smaller than gravity only much deeper than the line forming region: it is only deeper than the line forming region that Si is sufficiently in the rare gas configuration, that of Ne, for its radiative acceleration to be affected sufficiently. In the absence of mass loss Si is then expected to be supported and not to be very underabundant (Michaud et al. 1985).

In the presence of a small mass loss, the process described above for the λ Booti, stars occurs but much closer to the surface, where the radiative acceleration is smaller than gravity. As a function of time the abundance of Si then decreases in the atmosphere since it leaves by the wind but is not replenished by a flux from below. The results of detailed time dependant calculations are shown on Fig. 4b. For a mass loss rate of 2.5 10^{-15} $M_{\odot}$/yr, the Si abundance is reduced in the line forming region by more than four orders of magnitude after 10 000 yrs. In Fig. 4a is shown the space distribution of Si when it has about reached an equilibrium value. Its abundance goes down rapidly outward where the radiative acceleration is too small to support it. It reaches a minimum where the radiative acceleration has a maximum. This is because in the presence of an outward flux, the conservation of the Si flux leads to the abundance being smallest where the outward velocity is largest, that is where the radiative acceleration is largest (see Michaud et al. 1985 for details). If the mass loss rate is 4 times larger, the Si abundance is hardly reduced as can be seen from the equilibrium profile shown in Fig 4a. This qualitative difference in the solution is due to the sum of the diffusion and mass loss velocities changing sign in between. Whereas, in the absence of an abundance gradient, the net velocity is downward for the smaller of the two mass loss rates considered, it is upward for the larger mass loss. Mathematically there is a sign change in the differential equation and the nature of the solution changes. This occurs quite suddenly and so the underabundance of Si becomes a precise determination of the mass loss rate. If the mass loss rate is smaller, one expects that the time scale for the appearance of the anomaly will increase bacause it will take longer to empty the region where Si is supported, but then the underabundance should be larger. This remains to be checked by detailed calculations that are currently underway. The He, C and N abundances that such a mass loss rate leads to are also consistent with the observations (Michaud et al. 1985). We here only determine an upper limit to the mass loss rate, a lower limit is determined by the timescale of the sdB and sdO evolutionary phase. It is currently not known.

There is in our opinion no reason why stars should stop losing mass at the lowest currently detectable mass loss rate and so the hypothesis of a small mass loss rate is plausible. The existence of abundance anomalies puts very strong constraints as to how strong it can be.

5. LITHIUM UNDERABUNDANCES: EXTENSION OF THE AmFm PHENOMENON

Recent observations of Li in the F stars of the Hyades (Boesgaard and Tripicco 1985 preprint) have shown a most unexpected effective temperature dependance of the underabundance. It is sketched in Fig. 5. While the Li abundance is about normal in stars hotter than 7 000 K and in those around 6 200 K, it is underabundant by 2 orders of magnitude or more at 6 600 K with well defined intermediate values in between. Cooler than 6 000 K it shows the usual progressive reduction in the Li abundance.

It is relatively easy to see that diffusion is expected to lead to a dip in the Li abundance at about the observed temperature. On Fig. 5b is shown the effective temperature dependance of the depth of the He II convection zone and of the radiative acceleration on Li at the base of the He II convection zone. Slightly above 7 000 K, the convection zone is shallow and Li is supported by the radiation pressure in the hydrogenoid configuration. Below 7 000 K, the depth of the convection zone increases rapidly and Li is not supported any more at the bottom of the convection zone: it is completely ionized. Lithium then settles gravitationnally and becomes underabundant. As the temperature is further decreased, the depth of the convection zone continues to increase and the diffusion time scale increases, finally exceeding the age of the Hyades at an effective temperature of about 6 400 K (see Fig. 5 of Michaud et al. 1983). Gravitational settling then has no time to lead to underabundances in the cooler stars. The underabundances observed below 6 000 K are expected to be due to another process: the burning of the Li that has been transported to the Li burning region by turbulent diffusion (Vauclair et al. 1978).

Even though the parameter free model will always lead to the presence of such a dip, its properties depend on the details of the

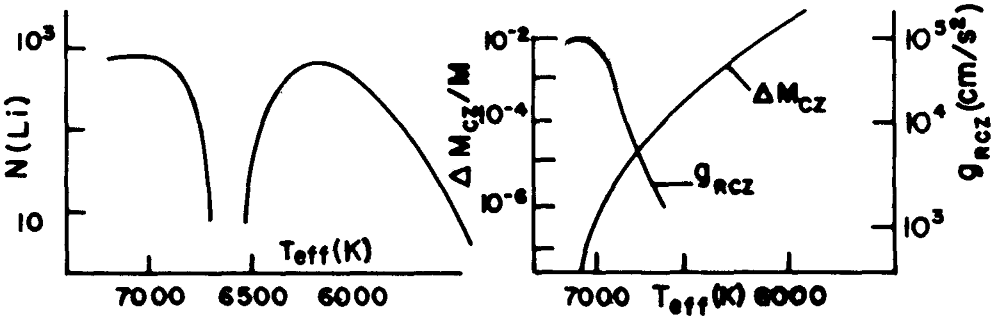

Figure 5. On part a) are sketched the results of Boesgaard and Tripicco (1985) for Li abundances (log N(H) = 12) in the Hyades. On part b) are shown, as a function of the effective temperature, both the depth of the convection zone (left hand scale) and the value of the radiative acceleration (right hand scale) at the bottom of the convection zone.

convection zones. In particular its exact location will depend on α, the value of the ratio of the mixing length and the pressure scale height. This is poorly known but we have used here $\alpha = 1.4$ as suggested by some evolutionary model calculations. Our argumentation has been based on static models but the time dependant calculations of the settling should really be carried out in evolutionary models that take into account the variation of the position of the bottom of the convection zone as the He abundance varies (Michaud, Fontaine and Beaudet 1984): if Li settles gravitationnally, so will helium. The dip will not be eliminated by changing α or taking evolution into account but its width will be changed and so will its depth. The precise position of the dip as well as its properties will turn out to depend on hydrodynamic properties which the Li underabundance will allow us to measure.

I would like to thank Dr Ann Boesgaard for communicating to me results ahead of publication.

REFERENCES

Alecian, G., and Michaud, G. 1981, Ap. J., 245, 226.

Alecian, G., and Vauclair, S. 1981, Astr. Ap., 101, 16.

Alecian, G., and Vauclair, S. 1983, Fundamentals Cosmic Phys., 8, 369.

Baglin, A. 1972, Astr. Ap., 19, 45.

Baschek, B., Kudritzki, R. P., Scholz, M., and Simon, K. P. 1982, Astr. Ap., 108, 387.

Borsenberger, J., Michaud, G., and Praderie, F. 1979, Astr. Ap., 76, 287.

______. 1981a, Ap. J., 243, 533.

______. 1984, Astr. Ap., 139, 147.

Borsenberger, J., Radiman, I., Michaud, G., and Praderie, F. 1981b, in Les étoiles de composition chimique anormale du début de la séquence principale, (Liège: Université de Liège), p.389.

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

Heber, U., Hamann, W.-R., Hunger, K., Kudritsky, R. P., Simon, K. P., and Méndez, R. H. 1984, Astr. Ap., 136, 331.

Kurtz, D. W. 1976, Ap. J. Suppl., 32, 651.

Lamontagne, R., Wesemael, F., Fontaine, G., and Sion, E. M. 1985, preprint.

Latour, J., Toomre, J., and Zahn, J.-P. 1981, Ap. J., 248, 1081.

Leckrone, D. S., 1981, Ap. J., 250, 687.

Michaud, G. 1970, Ap. J., 160, 641.

Michaud, G. 1976, in Physics of Ap Stars, IAU Colloquium No. 32, ed. W. W. Weiss, H. Jenkner, and H. J. Wood (Universitatsternwarte Wien, Vienna), p.351.

Michaud, G. 1980, A. J., 85, 589.

Michaud, G. 1981, in Les étoiles de composition chimique anormale du début de la séquence principale (Liège: Université de Liège), p.355.

Michaud, G. 1982, Ap. J., 258, 349.

Michaud, G., Bergeron, P., Wesemael, F., and Fontaine, G. 1985, Ap. J., in press.

Michaud, G., Charland, Y., Vauclair,S., and Vauclair G. 1976, Ap. J., 210, 447.

Michaud, G., Fontaine, G., and Beaudet, G. 1984, Ap. J., 282, 206.

Michaud, G., Mégessier, C., and Charland, Y. 1981, Astr. Ap., 103, 244.

Michaud, G., Montmerle, T., Cox, A.N., Magee N.H., Hodson, S.W., and Martel, A. 1979, Ap. J., 234, 206.

Michaud, G., Tarasick, D., Charland, Y., and Pelletier, C. 1983, Ap. J., 269, 239.

Osmer, P. S., and Peterson. D. 1974, Ap. J., 187, 117.

Preston, G. 1974, Ann. Rev. Astr. Ap., 12, 257.

Sadakane, K., and Jugaku, J. 1981, Pub. Astr. Soc. Pac., 93, 60.

Tassoul, J.-L., and Tassoul, M. 1982, Ap. J. Suppl., 49, 317.

Vauclair, G., Vauclair, S., and Michaud, G. 1978, Ap. J., 223, 920.

Vauclair, G., Vauclair, S., and Pamjatnikh, A. 1974, Astr. Ap., 31, 63.

Vauclair, S. 1975, Astr. Ap., 45, 233.

Vauclair, S., and Reeves, H. 1972, Astr. Ap., 18, 215.

Vauclair, S., and Vauclair, G. 1982, Ann. Rev. Astr. Ap., 20, 37.

Watson, W. D., 1971, Astr. Ap., 13, 263.

Discussion appears after the following paper.