LITHIUM ABUNDANCES, DIFFUSION AND MACROSCOPIC MOTIONS IN STELLAR CLUSTERS

Sylvie Vauclair
Observatoire Midi-Pyrénées
14, avenue Edouard Belin
31400 Toulouse
France

The "lithium gap" observed in the Hyades and other galactic clusters by Ann Boesgaard and her collaborators (Boesgaard and Tripicco 1986, Boesgaard 1987, Boesgaard, Budge and Burck 1987) gives a challenge to theoreticians. Indeed a good fit between the theoretical results and the observations will give a clue for our understanding of the stellar internal structure and evolution.

A theoretical explanation of the "lithium gap" by gravitational and radiative diffusion has been proposed by Michaud 1986. In G type stars, the convection zone is too deep for gravitational settling to take place : the density at the bottom of the convection zone is so large that the diffusion time scale exceeds the age of the star. Increasing the effective temperature leads to a decrease of the convection zone, and consequently to a decrease of the diffusion time scale (fig. 1). In F stars it becomes smaller than the stellar age, leading qualitatively to a lithium abundance decrease as observed. When the convection zone is shallow enough, the radiative acceleration on lithium becomes important as lithium is in the hydrogenic form of li III (while it is a bare nucleus, li IV, deeper in the star - (fig. 2). This radiative acceleration may prevent lithium settling for hotter F stars.

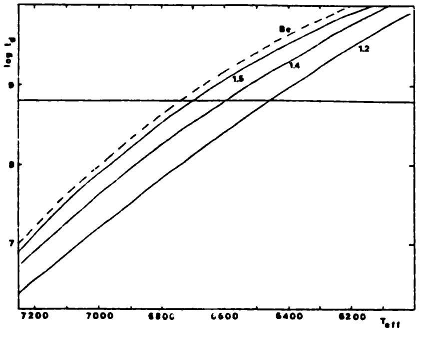

Fig. 1 : Time scales for gravitational settling at the bottom of convection zones in main sequence stars.
Solid lines = lithium, for α = 1.2, 1.4 and 1.5
Dasked line : beryllium, for α = 1.5

G. Cayrel de Strobel and M. Spite (eds.), The Impact of Very High S/N Spectroscopy on Stellar Physics, 463–468.

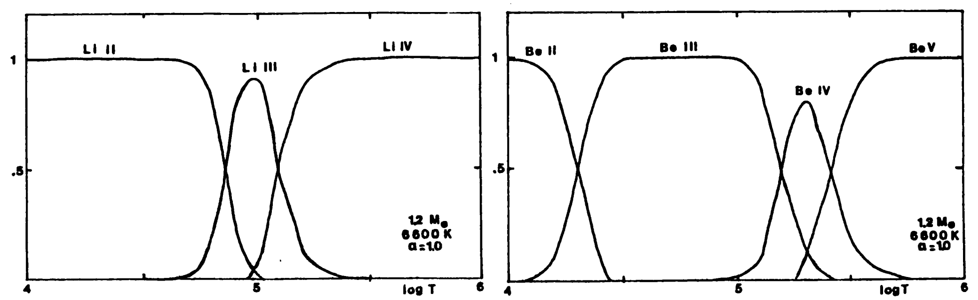

Fig. 2 : ionisation stages for lithium and beryllium in a $1.2\ M_{o}$ star, with $\alpha = 1.0$

This is a very attractive explanation, which leads to a minimum of the lithium abundance nearly at the place where it is observed in effective temperature. However it suffers from some difficulties : the theory predicts an increase of the lithium abundance larger than normal in the hottest F stars, which is not observed, and the predicted minimum lithium abundance is one or two orders of magnitude higher than the minimum observed in the Hyades. Also, this theory does not take any turbulence into account, while turbulence is definitly needed to explain the lithium abundance decrease in G stars (by mixing and nuclear destruction, see for example Cayrel et al 1984, Baglin, Morel, Schatzman 1985).

In the present paper we have focused on the problem of the computation of radiative accelerations, which are of prime importance in this theory. The radiative acceleration on a given element, through a bound-bound transition, may be written :

$$g_R = \frac{1}{m} \frac{N_{i,n}}{N} \int_0^{\infty} \sigma_{i,n} (\nu) \frac{\phi\nu\ d\nu}{c} \tag{1}$$

where m is the mass of the considered element, $N_{i,n}/N$ the fraction of the element in the lower level of the line, $\sigma_{i,n}$ (ν) the transition section and $\phi_\nu\ d\nu$ the available photon flux.

With the diffusion approximation, a lorentz profile for the line, and after integration over ν, g_R becomes :

$$g_R = \frac{1}{mN} \frac{8\pi^2\ k^3}{3h^2\ c^3} T^2 \left(-\frac{dT}{dr}\right) \frac{z^4\ \ e^z}{(e^z - 1)^2} \frac{\Delta/2}{\sqrt{\frac{\kappa_c}{\kappa_L}\left(\frac{\kappa_c}{\kappa_L} + 1\right)}} \tag{2}$$

with

$$z = \frac{h\nu}{kT} \quad \text{and} \quad \kappa_L = N_n \frac{\pi e^2}{m_e c} \frac{f}{\pi} \frac{2}{\Delta}$$

where f is the oscillator strength of the line and $\Delta/2$ the half width.

κ_c is the monochromatic opacity due to all the opacity sources except the considered line.

For an unsaturated line ($\kappa_L \ll \kappa_c$), (2) may be transformed into :

$$g_R = \frac{1.6\times10^{-4}}{A} \frac{N_{i,n}}{N} f \frac{z^4 e^z}{(e^z-1)^2} \frac{T_e^4}{T} \frac{R^2}{r^2} \frac{\bar{\kappa}}{\kappa_c} \qquad (3)$$

where $\bar{\kappa}$ is the Rosseland mean opacity

T_e the effective temperature
T the local temperature
R the stellar radius
r the local radius

The ratio $\bar{\kappa}/\kappa_c$ which appears in g_R represents the fact that the radiative acceleration through one line strongly depends on the other sources of opacity at the same frequency. Up to now, the radiative accelerations have been computed with the approximation $\kappa_c \approx \bar{\kappa}$. However if, for example, a line of an abundant element sits at the same place as the Ly α lithium resonance line, the radiative acceleration on lithium may be strongly decreased.

Lithium					Beryllium				
	ion	λ	level (eV)	f		ion	λ	level (eV)	f
	O V	134.473	19.7			Mg VI	75.834	0.0	0.01
	"	135.175	19.7			"	75.890	0.0	0.01
	"	135.523	0.0	0.016		Mg VII	75.975	5.1	
Lyα	Ne V	134.48	0.0		Lyα	Al VII	75.846	0.0	
135.0Å	"	134.84	7.9	0.01	75.93Å	Al VIII	75.894	0.2	
	Fe VII	134.940	3.6			"	75.985	0.5	
	"	135.488	3.6			Fe V	75.685	0.0	
						"	76.006	0.0	
	Mg V	113.703	0.0	0.12		Mg VII	64.12.	5.08	
	"	113.934	0.22	0.01		"	64.38	5.08	
	"	113.990	0.0	0.03		Mg VIII	64.24	0.0	
	"	114.059	0.0	0.17		"	64.38	0.4	
	"	114.183	0.22	0.02		Si VIII	63.88	0.0	
Lyβ	"	114.199	0.22	0.06	Lyβ	"	63.90	8.6	
113.94Å	Ne VI	113.95	0.16		64.06Å		64.28	8.6	
	"	114.07	0.0			Al VIII	63.93	0.0	
	"	114.13	0.0			"	63.96	0.2	
						"	64.004	0.55	
						"	64.086	0.55	
						Fe XIII	64.139		
						Fe XIV	63.96		

Sources :
Kelly 1973 and 1982, Kurucz and Peytremann 1975, Wiese 1985

A table of the important lines which may blend the lithium and beryllium resonance lines is given above. This table is not exhaustive as this part of the spectrum is not well known. Also the atomic parameters of these lines are very uncertain. As a quantitative result cannot be given without more precise atomic parameters, let us discuss here what would happen if the radiative acceleration on lithium was strongly overestimated : then the theoretical minimum would be smaller and could possibly match the observations. The red part of the "lithium gap" could be well explained with an α parameter (ratio of the mixing length to the presure scale height) of 1.2 (fig. 3).

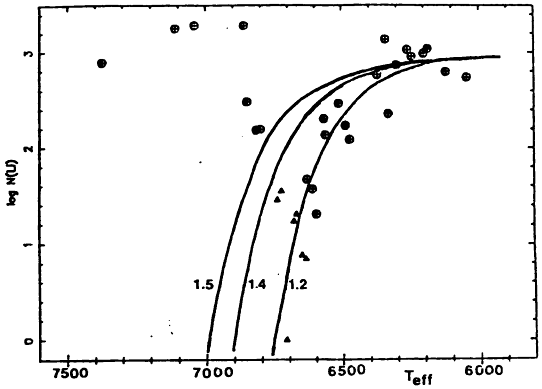

Fig. 3 : Lithium depletion by gravitational settling alone, compared with Boesgaard and Tripicco 1986 observational data

However the radiative acceleration alone would not be sufficient in this case to account for the increase of the lithium abundance back to normal in the hotter F stars.

Macroscopic motions could be invoked to explain this feature : either turbulence induced by rotation (as the rotation velocity in stars increase from G to F stars, Benz et al 1985 ; Boesgaard 1987) or mass loss.

Observational tests of these scenarii can be found in the observation of beryllium : if the lithium feature is entirely due to gravitational and radiative diffusion as proposed by Michaud 1986, beryllium should also show a minimum, less deep than the lithium one and at a smaller effective temperature (as beryllium is in the hydrogenic form deeper than lithium see fig. 1).

On the other hand, the lithium and beryllium minima would be at the same place if macroscopic motions were the reason for their abundance increase back to normal in F stars.

More spectroscopic observations, and more atomic parameters for the far UV line are needed before reaching any precise conclusion.

Acknowledgements

Thanks are due to Marie-Christine Artru for many fruitful discussions and help in my search for atomic parameters.

References

Baglin,A., Morel,P., Schatzman,E. 1985, Astron. Astrophys. 149, 309

Benz,W., Mayor,M. Mermilliod,J.C. 1984, Astron. Astrophys. 138, 93

Boesgaard,A.M., Tripicco,M.J. 1986, ApJ 302, L49

Boesgaard,A.M., Budge,K.G., Burck,E.E. 1987, preprint

Boesgaard,A.M. 1987, P.A.S.P., in press

Boesgaard,A.M. 1987, ApJ, in press

Cayrel,R., Cayrel de Strobel,G., Campbell,B., Däppen,W. 1984, ApJ 283, 205

Kelly,R.L. 1973 and 1982 "Atomic and Ionic spectrum line below 2000 Å", office of fusion energy, ORNL 5922

Kurucz,R.L. Peytremann,E. 1975 "Table of semi empirical g f values" Smithsonian Astrophysical Observatory Special report 362

Michaud,G. 1986, ApJ 302, 650

Wiese,W.L. 1985, "Atomic data for fusion" ORNL 6089

https://doi.org/10.1017/S007418090003549X Published online by Cambridge University Press

DISCUSSION

BOESGAARD A comment: These are very important calculations for the interpretation of the Li dip in the F stars. I would like to say that thanks to the high technology at this meeting I can give you a new constraint for the theoretical calculations. I got a computer message this morning from my student at Caltech on the Li dip in the Pleiades cluster. It is not nearly as deep apparently as that in the Hyades. It goes down to perhaps log N(Li) = 2.5. This is consistent with the fact that the Pleiades are an order of magnitude younger than the Hyades so diffusion has not had as long a time to operate.

https://doi.org/10.1017/S007418090003549X Published online by Cambridge University Press