Radial and Nonradial Pulsations as Probes of Stellar Physics
ASP Conference Series, Vol. 259, 2002
C. Aerts, T.R. Bedding, & J. Christensen-Dalsgaard, eds.

Internal Dynamics of Slowly Rotating Stars: the Effect of μ-Gradients on the Meridional Circulation

S. Théado, S. Vauclair

Laboratoire d'Astrophysique, Observatoire Midi-Pyrénées, Toulouse, France

Abstract. In slowly rotating stars, the coupling of helium settling and meridional circulation leads to a particular hydrodynamical process which was not introduced in previous computations of abundance variations. The μ-gradients induced by element settling can lead to a quasi-paralysis stage in which the efficiencies of both the meridional circulation and the microscopic diffusion are strongly reduced. Such an effect was studied in the eighties for nuclear-induced μ-gradients by Mestel et al., who called it "creeping paralysis". Below convective zones, this process has important consequences. Here we discuss the case of the halo stars and the sun.

The meridional circulation velocity in stars, in the presence of μ-gradients, is the sum of two terms, one due to the classical thermal imbalance (Ω-currents) and the other due to the induced horizontal μ-gradients (μ-currents). In the most general cases, μ-currents are opposite to Ω-currents. In previous computations of rotation-induced mixing, these μ-currents were not taken into account. Figure 1

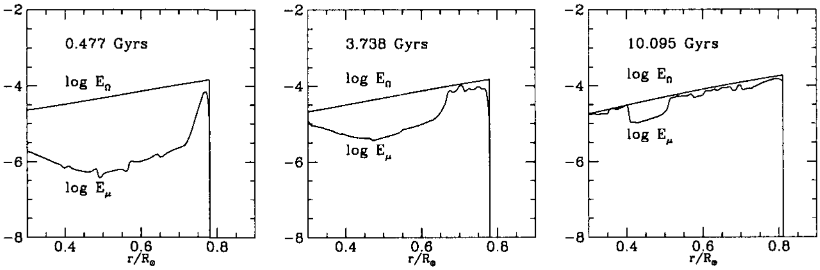

Figure 1. Computations of the Ω-currents (E_Ω) and μ-currents (E_μ) below the convective zone in a $0.70 M_\odot$ halo star with [Fe/H]=-2, V_{rot}=5 km.s^{-1} and $\alpha = 1.79$.

shows the evolution of Ω- and μ-currents with time in a $0.70 M_\odot$ halo star: on a time scale of the order of 1 gyr, the μ-gradients are large enough to create μ-currents of the same order as Ω-currents. Then a kind of "creeping paralysis", in which the effects of both circulation and element diffusion are strongly reduced, can settle below the convective zone. In Théado & Vauclair (2001), we have

https://doi.org/10.1017/S0252921100015554 Published online by Cambridge University Press

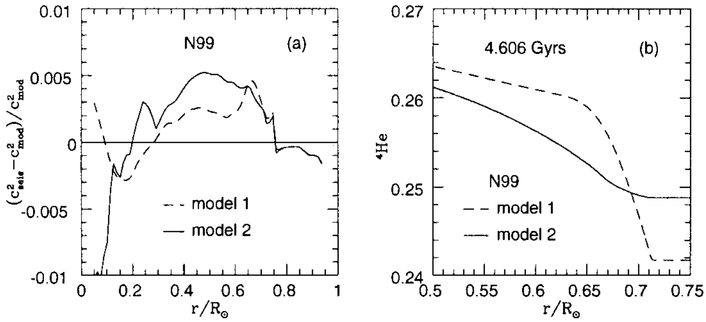

Figure 2. Influence of the diffusion-circulation coupling.(a): comparison of the seismic sound speed (c^2_{seis}) and that of the model (c^2_{mod}). (b): He profiles near the base of the convective zone.

shown that this paralysis can account for both the lithium plateau and the small dispersion of the lithium abundances.

In the solar case, it has been known for several years that the mixing processes below the solar convection zone must be limited to a small depth. This is necessary to account for the constancy of the ^{3}He/^{4}He ratios these last 3 Gyrs and to be consistent with helioseismic results. In previous works (e.g. Richard et al., 1996), a critical μ-gradient was arbitrarily introduced to stop the mixing at a given depth. The diffusion-circulation introduced in our computations reproduces in a more natural way the mixing cut-off for a critical μ-gradient. We present two solar models including the new European Nuclear Astrophysics Compilation of REaction rates : model 1 with pure element segregation, model 2 with segregation, our diffusion-circulation coupling and a tachocline parametrised by an exponential mixing. The tachocline parameters are adjusted to reproduce the observed lithium depletion and the mixing parameters to obtain, below the convective zone, a smooth helium gradient consistent with helioseismic observations. Then we obtain a well calibrated model with a tachocline thickness consistent with helioseismic inversions. The ^{3}He/^{4}He ratio constraint is satisfied and the value of $Y_{\rm surf} = 0.2488$ is consistent with helioseismology. Fig. 2 shows that the spike in the sound velocity observed in the case of pure element settling is smoothed down.

This effect will be computed for other stars and could possibly be tested in future asterosismological experiment. For the sun, it suggests a horizontal variation of the μ-gradient below the convective zone, which could be searched for in helioseismology.

References

Théado, S. & Vauclair, S. 2001, A&A, 375, 70

Richard, O., Vauclair, S., Charbonnel, C., & Dziembowski, W. A. 1996, A&A, 312, 1000