ON THE PRESENCE OF TURBULENT DIFFUSION IN STARS AND ITS EFFECT ON STELLAR EVOLUTION

E. SCHATZMAN
Observatoire de Nice
B.P. 252 - Nice-Cedex 06007 - France

The presence of a mild turbulence inside rotating stars has been considered by Howard et al (1967) and by Bretherton et al (1968) in connection with the problem of the solar flattening, raised by Dicke (1970). The possibility of using abundance determination to test the existence of that turbulence has been considered by Schatzman (1969).

It is only in 1977 that the interpretation by Schatzman (1977) of the abundance determination of lithium in giants by Alschuler (1975) has brought a reasonable proof of the existence of a mild turbulence deep in stars. The presence of a mild turbulence at greater depths was established by Genova and Schatzman (1979) by a consideration of the (12C/13C) ratio in giants.

Further proof is given by the consideration of the solar neutrino flux. Schatzman and Maeder (1980) have shown that turbulent diffusion brings H and 3He in the solar core. The effect is to reduce the central temperature of the Sun, with the consequence of a drastic decrease of the neutrino flux. It leads also to an explanation of the surface 3He abundance and fullfills the constraint on the solar luminosity.

For all these effects, the turbulent diffusion, supposed to be due to some marginal Reynolds instability, induces a turbulent diffusion coefficient $D_T = Re^* \nu$. A rough estimate by Schatzman (1977) for a Kolmogoroff spectrum leads to $Re^* = 100$ to 200. If Re^* is considered as a purely phenomenological parameter, the various astrophysical estimates agree with a value $Re^* = 100$ to 200.

Evolution of a 1 $M_\odot$ star has been computed by Maeder (1980) with turbulent diffusion mixing. The star does not evolve towards the first ascending branch of the giants, but becomes a blue straggler. An inhibition of the turbulence has to be introduced to provide the evolution towards the giant branch. This is probably due to the stabilization by the μ-gradient.

These results suggest important modification to stellar evolution patterns.

D. Sugimoto, D. Q. Lamb, and D. N. Schramm (eds.), Fundamental Problems in the Theory of Stellar Evolution, 281–283.
Copyright © 1981 by the IAU.

https://doi.org/10.1017/S0074180900074076 Published online by Cambridge University Press

DISCUSSION

Roxburgh: I can see a problem in trying to explain the solar neutrino problem by such diffusion. In order to lower the neutrino flux, the diffusion has to be strong enough to keep the sun more or less homogeneous. This then raises a problem in explaining the agreement between inhomogeneously evolved models and observations of globular clusters.

Schatzman: This raises problem of the blue stragglers. If nothing happens, and if diffusion is not turned off, a star would evolve more or less in the direction of the blue stragglers and would never reach the giant branch. It is necessary for most of the stars to turn off turbulent mixing at some proper time. It seems that the assumption that turbulent diffusion stops when the μ-gradient exceeds a certain critical value, which might be related to the angular velocity, is quite reasonable. There would be at least two classes of stars: those which keep experiencing mixing, and those for which mixing stops at some time.

Roxburgh: What mechanism do you think drives the weak turbulence? I would like to suggest that one attractive possibility for driving diffusion is the instability driven by the build-up of ^{3}He away from the centre. Diffusion could then keep the sun on the verge of instability until such time as the chemical inhomogeneity stabilised the sun and suppressed the weak turbulence.

Schatzman: I am interested in this possibility, which might prevent the ^{3}He peak from becoming too large and thus would limit the amount of ^{3}He which is driven by turbulent diffusion to the surface. On the other hand, I have been thinking that magnetic braking is followed by a continuous redistribution of angular momentum inside the sun and that, as supposed by Spiegel and co-workers, some sort of turbulence takes care of the process.

Castellani: I am a bit surprised by your statement about the influence of central ^{3}He on the decrease of the central temperature in Sun. It seems to me that in the central region the ^{3}He-abundance is determined only by the equilibrium conditions. This is just because the characteristic time scale to reach ^{3}He equilibrium is much shorter than the time scale for turbulent diffusion. So I suggest that the decrease in temperature is driven by the increase in H, and that a (small) increase in ^{3}He is only the consequence of such a decrease.

Schatzman: In order of magnitude, the excess of ^{3}He can be written:

$$\frac{\Delta X_3}{X_3} = \frac{1}{2}\,\frac{3D_t (X_3)_{peak}}{R_c^2}\,\frac{1}{K_{11} X_1^2 A_3 m_H} \,,$$

with $(X_3)_{peak} = 2.4 \times 10^{-3}$, $(R_c/R_\odot) = 0.3$, and $D_t = 100$. We obtain

$$\frac{\Delta X_3}{X_3} \cong 0.085 \,.$$

https://doi.org/10.1017/S0074180900074076 Published online by Cambridge University Press

The direct calculation gives

$$(X_3/X_1)_{\text{balance}} = 3.44 \times 10^{-5}$$

$$(X_3/X_1)_{\text{diffusion}} = 3.7 \times 10^{-5} \quad (D_t = 100)$$

where $(X_3/X_1)_{\text{balance}}$ has been calculated for the central temperature of the diffusion model. It is not the diffusion time which is important, but the flow, which depends on both D_t and ∇X_3.

Massevitch: Have you considered the possibility that the use of evolutionary sequences other than Iben's, with slightly different chemical compositions and/or other opacity tables, may change the estimated Li-deficiencies so that they coincide better with the observed values?

Schatzman: Without diffusion, all models for the giants lead to a plateau followed by sudden drop of the Lithium abundance as soon as the convective zone has become deep enough to reach the level at which Li is burnt. This is complete disagreement with the observations, which show as a general trend a continuous decrease of the Lithium abundance as a function of spectral type.

https://doi.org/10.1017/S0074180900074076 Published online by Cambridge University Press