Dredge-up by Sound Wave Emission from a Convective Core

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Concerning the scsattering of OB stars in the HR diagram (Humphry 1980), the effects of overshooting of convective core (Maeder 1984), mass loss (cf. Chiosi and Maeder 1986), and generous stability criterion of semi-convection (Stothers and Chin 1976) have been discussed. Here, we will note the dredge up effect is caused by the sound waves emitted from a convective core.

The sound mode of nonradial oscillation, with the spherical harmonics $Y_{\ell m}(\theta, \phi)$ and the frequency ω, can exist in the propagation zone, where the bottom boundary locates at the position of $\omega = L_\ell$ [$=\sqrt{\ell(\ell+1)}c_s/r$], and the upper boundary does near the photosphere. Here, L_ℓ is called as the Lamb frequency, and c_s is the sound velocity.

In early type stars, the bottom boundary penetrates into convective core (Osaki 1975). Accordingly, convective motion of eddies excites sound waves, as in the case of acoustic noise emmision from imcompressible turbulence, shown by Lighthill (1978). Since the frequency of excited waves is higher than the Brunt-Väisälä frequency at the photosphere, the waves are not trapped, but running outward (cf. Unno et al 1979).

If the random displacement of generated wave is denoted by ξ, it causes first order fluctuation of mean molecular weight μ_1, given by $-\xi_r \partial \mu_0/\partial r$, where μ_0 is the unperturbed distribution of mean molecular weight. Then, the nonlinear coupling between ξ and μ_1 produces the convective effect for the mean molecular weight, originated from the term of $(\mathbf{v}_1 \cdot \nabla)\mu_1$, where $v_1 = \partial \xi/\partial t$.

If we take time average over shorter period than an evolutional time scale and over spherical angular average, we obtain the evolutional equation for the averaged mean molecular weight $\bar{\mu}$;

$$\frac{\partial \bar{\mu}}{\partial t} + (v_{ev} + v_{wind})\frac{\partial \bar{\mu}}{\partial r} = -C(r)\frac{\partial \bar{\mu}}{\partial r} ,$$

where $$C(r) = -<(\mathbf{v}_1 \cdot \nabla)\xi_r>,$$

and v_{ev} and v_{wind} means the velocity field of evolutionally secular change and the interior component of stellar wind. It should be noted the diffusion term of $<v_r \xi_r> \partial^2 \bar{\mu}/\partial r^2$ vanishes in this sound mode case, because v_r and ξ_r are in orthogonal phase to each other. The effect of diffusion has been considered by Schatzman (1977), in the case of late typestars, and by Langer

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et al (1985), in the case of semiconvection zone of massive stars.

Now, it is proved after some manupilation of sound modes that

$$C(r) = \frac{1}{\Gamma_1 p_0} < p' v_r >,$$

where p_0 is the unperturbed pressure, p' a pressure perturbation of sound mode, and Γ_1 the specific heat ratio. Consequently, the convective coefficient C is proportional to the acoustic power $< p' v_r >$, which has been fully considered in the case of the isothermal atmosphere (Stein 1967). In this problem, the exciting region for sound waves locates from the bottom boundary of propagation zone to the edge of convective core. This region is wider for higher frequency waves. However, energy densities of exciting eddies decrease in the high frequency case.

The mode of $\ell = m$ has the largest amplitude, which is determined by the forth order correlation of turbulent velocity $< u_i u_i u_i' u_i' >$, and there are monopole, dipole and quadrupole emmisions for each spherical harmonics, with regard to the radial direction (cf. Unno 1964). The mode of low ℓ contributes to the monopole emmision, but that of high ℓ to the latter ones, as the same as in the isothermal case.

Now, strong stellar wind blows on the photosphere of early type stars (cf. de Jager 1980), so that mass outward flow v_{wind} up to 1 cm/sec exists in the edge of core. The precise consideration is required to determine whether the convective velocity of C is more effective for dredge-up than v_{wind} or not. Quantative results will be shown in the seperate paper.

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