Stellar atmospheric instability in the upper part of the Hertzsprung-Russell diagram

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The upper limt of stellar luminosity in the Hertzsprung-Russell diagram is a line running approximately from (log T_{eff}; log $(L/L_\odot)$) = (4.5; 6.3) via (4.0; 5.74) to (3.5; 5.7) (Humphreys and Davidson, 1979; Humpreys, 1983). Since Eddington (1921) this limit has been associated with the Eddington condition

$$g_{grav} + g_{rad} = 0, \text{ or } g_{grav}(1-\Gamma) = 0, \qquad (1)$$

where Γ_E is the Eddington factor. But Eddington's criterion appears not to describe the actually observed limit. In addition it does not work for cool stars. One of us (De Jager, 1978, 1980) has therefore introduced another limit

$$g_{grav}(1-\Gamma) + g_{turb} = 0, \qquad (2)$$

with $g_{turb} = \rho^{-1} dP_{turb}/dz$. It can be shown (De Jager, 1984) that condition (2) is equivalent to

$$F_m = \left(\frac{\Gamma \mathcal{R}}{\mu}\right)^{\frac{1}{2}} g_{grav}\, T_e^{\frac{1}{2}} \left(\frac{\bar{\tau}}{\kappa}\right)(R)(1-\Gamma_E), \qquad (3)$$

if we assume that the mechanical flux F_m dissipates fully within one scale height, an assumption that is justified since in near-unstable stellar photospheres the turbulent velocity v_t is approximately equal to the sound velocity s. Indeed, further elaboration of Equation (3) shows (De Jager, 1984) that this Equation is equivalent with the condition that in the photospheres of stars near the atmospheric instability limit:

$$v_{turb} = s. \qquad (4)$$

In this paper we want to show that Equations (3) and (4) are approximately correct near the stellar instability limit. We will consider this as a justification of the instability condition (2).

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1. From literature data on microturbulent velocities in seven very luminous stars we derived a fair correlation between $\log(v_{turb}/s)$ and $\log(L_{star}/L_{limit})$, where L_{lim} is the luminosity limit at the same T_{eff}-value as the star. The regression relation is

$$\log(v_t/s) = 0.54 + 0.85 \log(L/L_{lim}), \qquad (5)$$

(correlation coefficient: 0.6) which shows that the turbulent atmospheric velocity indeed increases strongly with increasing luminosity, and moreover that $v_t = s$ is already reached at $\log(L/L_{lim}) = -0.6$: hence, intrinsically brighter stars and <u>a fortiori</u> stars at the instability limit have supersonic photospheric turbulence, which explains their atmospheric instability.

2. A further check is the following. It is implicitely assumed that an increase of v_t for increasing luminosity causes an increase of the rate of mass-loss. If that is true, stars with the same values of T_{eff} and L but with different v_t values should have different $\dot{M}$-values. From a recent review of mass-loss data (De Jager et al., 1985) it appeared that for all O- to M-type stars $\dot{M}$ is a function $\dot{M}(T,L)$ of T_{eff} and L only; the histogram of deviations in $\log(\dot{M})$ has a sigma of 0.53. We examined if the differences $\Delta \log \dot{M}$ between $\log(\dot{M})_{observed}$ and the function values $\log \dot{M}(T,L)$ are correlated with $\log(v_t/s)$ and found a positive correlation (correlation coeff = 0.7):

$$\Delta \log \dot{M} = -0.04 + 2.35 \log (v_t/s), \qquad (6)$$

which shows that, all other parameters remaining the same, the rate of mass loss appears to increase very strongly with v_t.

3. As a last check we assumed (tentatively, and not fully justifiable) that all dissipated mechanical flux goes into kinetic energy of the stellar wind, hence

$$4\pi R^2 F_m = \tfrac{1}{2} \dot{M} v_\infty^2, \qquad (7)$$

and found that the $\dot{M}$-values thus calculated, with F_m according to Equation (3), agree reasonably well with observed values.

Conclusion: The three evidences listed above under 1, 2, and 3 support the validity of our instability criterion (2), and the consequent relations (3) and (4).

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