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Areas of atmospheric instability in the Hertzsprung-Russell diagram

ABSTRACT

We have developed an iterative algorithm for computing the net sum of various accelerations working on a stellar atmosphere at a specified height level. Thus, two areas of atmospheric instability are found. One is for redward evolving stars; It coincides well with the observed upper limit of stellar existence. The other is for blueward evolving stars; it is an area situated around $T_{eff} \approx 8000$ K and $\log(L/L_{\odot}) = 5.7$, and may be responsible for the yellow supergiants.

ACCELERATIONS IN A STELLAR ATMOSPHERE

The forces acting on a volume of matter in a stellar atmosphere are defined by Euler's equation of the conservation of momentum

$$\rho\left(\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial z}\right) - \rho g - \frac{\partial P}{dz} = 0 \quad (1)$$

where z is the vertical distance, t is time, ρ the mass density, v the gas velocity, g the gravitational acceleration, and P the total pressure, being the sum of gas pressure, radiaition pressure, shock wave pressure and shock momentum pressure:

$$P = P_{gas} + P_{rad} + P_{sw} + P_{sm} \quad (2)$$

Expressions for P_{sw} and P_{sm} are given by Gail, Cuntz and Ulmschneider (1990). The term $\partial v/\partial z$ represents the stellar wind effect, and $\partial v/\partial t$ represents the effect of mass motion, due to non-linear atmospheric pulsations (gravity waves). The net effect of all accelerations discribed in eqs (1) and (2) is

$$g_{eff} = g_{grav} + g_{rad} + g_{sw} + g_{sm} + g_{wind} + g_{puls} \, . \quad (3)$$

STABILITY CALCULATIONS

First stability calculations were made on the basis of eq.(3), however excluding the time-dependent term

$$g_{puls} = \partial v/\partial t$$

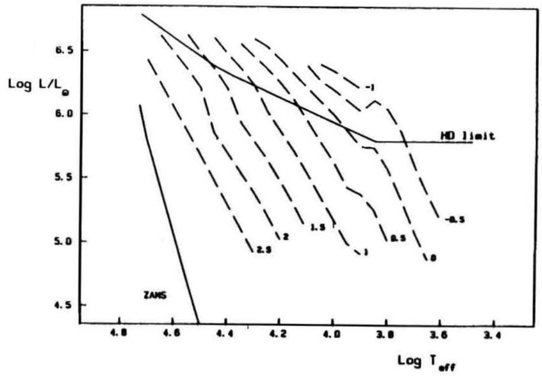

Figure 1: Effective acceleration in stellar atmospheres at $\tau_R = 0.03$, calculated assuming $g_{puls} = 0$ for stars evolving redward. No instability limit is reached because these stars are able to adjust themselves during their evolution

The procedure is an iterative one based on a simultaneous solution of eq.(3) with $g_{puls} = 0$ and

$$\begin{aligned} P_{gas}(\tau) &= \int_z^\infty g\rho dz \\ \tau &= \int_z^\infty \rho dz \\ \kappa &= \kappa(T, P_g) \\ T(\tau) &= f(T_{eff}, g_{eff}, \tau) \, . \end{aligned}$$

The calculations were made for one reference optical depth for which we chose $\tau_R = 0.03$. It appears, as can be expected, that in no case $g_{eff} > 0$ (meaning instability) because if the characteristic time of stellar atmospheric evolution exceeds the dynamic time scale of the atmosphere the latter always adjusts to a situation with a negative (meaning stable) g-value. This is shown in Fig.1 for redward evolving stars.

The inclusion of the term g_{puls} adds a destabilizing element. If A is the average velocity amplitude and P the average period of the gravity waves then the average outward acceleration over half a wave period is $g_{puls} = 4A/P$ when at any time one-third of the stellar surface has an outward directed net acceleration.

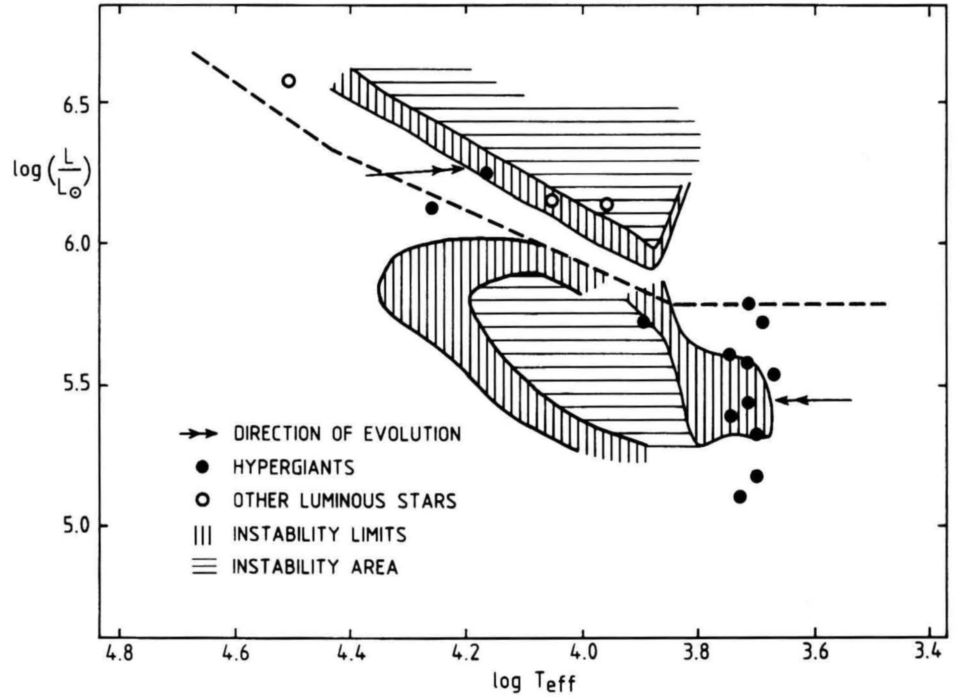

Figure 2: areas of instability in the HR diagram. The upper instability region is for redward evolving stars; the lower is for blueward evolving ones

INSTABILITY LIMITS

There appears to exist two area of instability. Their limits are drawn in Figure 2, where they are marked by an uncertainty band (hatched vertically). Redward evolving stars, still having a large mass, meet the first limit which coincides fairly well with the observed upper limit of stellar existence. Blueward evolving stars have much smaller mass; their atmospheres appear to become instable in an *area* around the point $\log T_{eff} = 3.9$ and $log(L/L_{\odot}) = 5.7$.

It is perhaps significant that most of the hypergiants occur to the right of this area, and that they have, on the average, a rate of mass loss that is 3 to 10 times larger than that of other stars in adjacent parts of the HR diagram.

REFERENCES

Gail, H.-P., Cuntz, M., and Ulmschneider, P.: 1990, A&A 234, 359

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