Astron. Astrophys. 317, 121–124 (1997)

ASTRONOMY AND ASTROPHYSICS

The effect of turbulent pressure on the red giants and AGB stars

II. On the mechanism powering the strong stellar winds

S.Y. Jiang and R.Q. Huang

Yunnan observatory, Chinese Academy of Sciences, P.O. Box 110, 650011 Kunming, P.R. China

Received 24 January 1996 / Accepted 7 May 1996

Abstract. A criterion for the occurrence of dynamical instability in the convective envelopes of red giants and AGB stars is presented. Using this criterion we find that the effect of turbulent pressure causes the dynamical instability in the regions very close to the sufaces of red giants and AGB stars, which affect the mass ejection outwards. This may be the mechanism powering the strong stellar winds of red giants and AGB stars with very low surface temperature and faint radiation pressure.

Key words: stars: AGB – stars: mass loss – instabilities

1. Introduction

An important property of red giants and AGB stars is that they have strong stellar winds. The rates of mass loss due to stellar winds have the values of $10^{-7} - 10^{-6} M_\odot \ yr^{-1}$ for the red giants and of $10^{-5} - 10^{-4} M_\odot \ yr^{-1}$ for the AGB stars. The latter is otherwise known as superwind (cf. Renzini 1981 and reference therein). The mechanism driving the strong stellar winds from the stars with very low surface temperature and faint radiation is still a matter of debate. For the cool red giants several theoretical models have been suggested to explain the great mass loss. These can be grouped into the following categories according to the powering mechanism: radiation pressure on dust grains (atoms,molecules); driving by wave pressure; driving by shock waves; and finally the pressure of hot gas powers the wind (cf. Castor 1981). For the AGB stars three suggestions can be found for the mechanism powering superwind that are based on the effect of envelope pulsations.

(i) AGB stars may go through a phase of large amplitude radial pulsations, which may strongly enhance the mass loss rate (Wilson and Hill 1979; Wood 1979,1981; Wood et al.1983).

(ii) Pulsational models of AGB stars suggest that superwind might be caused by switching of pulsation from the first overtone to the fundamental mode, perhaps giving rise to sporadic episodes of mass ejection (Wood 1974;Tuchman et al.1979).

Send offprint requests to: R.Q. Huang

(iii) Pulsation-radiation pressure can induce envelope ejection (Wannier 1984; Wilson and Kowalsky 1987; de Jager and Nieuwenhuijzen 1988; Wood and Vassiliadis 1992; Feast 1992; Vassiliadis and Wood 1992).

Furthermore, superwind can be caused by large-scale instabilities occurring on dynamical time scales(Lucy 1967; Paczynski and Ziolkowski 1968; Han et al.1994).

In all the above investigations the contribution of turbulent pressure is neglected. However, if the turbulent pressure becomes important in the convective envelopes of red giants and AGB stars, the effect of turbulent pressure can cause not only a change in the internal structure, but also dynamical instabilities in the regions close to the surfaces which may affect mass ejection outwards.

The purpose of this paper is to investigate the mechanism driving strong stellar winds from the red giants and the AGB stars. In order to understand the occurrence of dynamical instabilities in the convective envelopes,we present at first a criterion for the dynamical instability. Using this criterion we discuss whether dynamical instabilities can occur or not in the regions close to the surfaces of these stars, which finally affect the mass ejection outwards.

2. The criterion for the occurrence of dynamical instability in the convective envelope

The dynamical instability occurs in a region of the convective envelope, if there the sum of the outwards accelerations due to radiation and turbulent pressure exceeds the inward gravitational acceleration. This can be expressed as

$$g_R + g_t - g \geq 0, \tag{1}$$

where the inward gravitational acceleration is

$$g = \frac{GM_r}{r^2}, \tag{2}$$

the outward acceleration by radiation is

$$g_R = -\frac{1}{\rho}\frac{dP_R}{dr}, \tag{3}$$

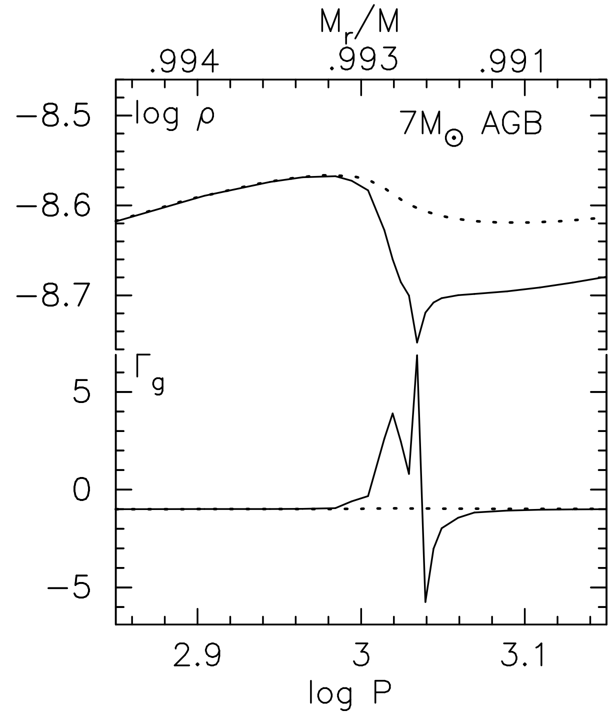

Fig. 1. The changes in the density ρ and the value of $\Gamma_g (\equiv \frac{g_R+g_t-g}{g})$ in the envelope of an AGB star of $7M_\odot$. The solid and the dotted curves indicate the cases with and without the consideration of turbulent pressure respectively.

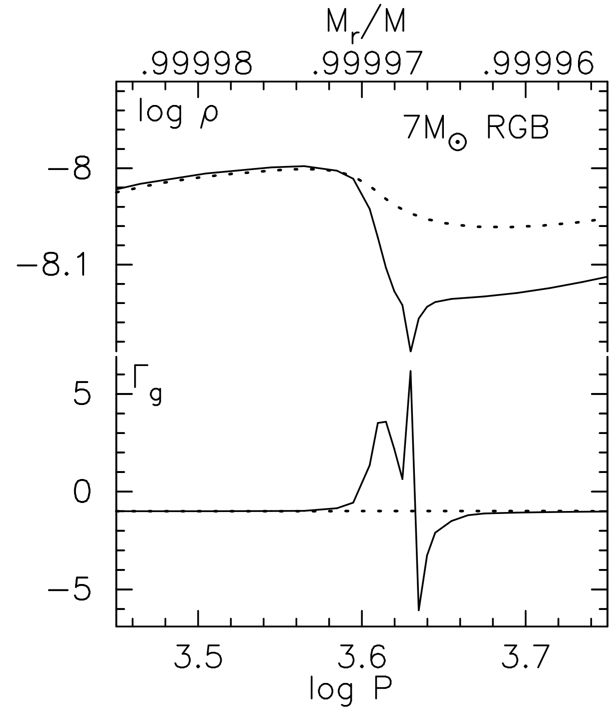

Fig. 2. The changes in the density ρ and the value of Γ_g in the envelope of a red giant with $7M_\odot$. The solid and the dotted curves have the same meaning as in Fig. 1.

and the acceleration by turbulent pressure is

$$g_t = -\frac{1}{\rho}\frac{dP_t}{dr}, \tag{4}$$

P_R and P_t are the radiation pressure and the turbulent pressure, respectively. The motion of the gas element in the dynamical instable region conforms to the equation of

$$\rho\frac{dv}{dt} + \frac{dP_g}{dr} = -\rho g - \frac{dP_R}{dr} - \frac{dP_t}{dr}, \tag{5}$$

where P_g is the gas pressure, and v is the velocity of the gas element.

In the stellar model calculations one assumes, however, that all the regions in the star are in the hydrostatic equilibrium and conform to the equation of

$$\frac{dP_g}{dr} = -\rho g - \frac{dP_R}{dr} - \frac{dP_t}{dr}. \tag{6}$$

This means that in the dynamical instable region, in which both Eqs. (5) and (6) and the condition (1) exist, the time depending term in Eq. (5) is neglected artifitially. Therefore, from condition (1) and Eq. (6) one obtains

$$\frac{dP_g}{dr} > 0. \tag{7}$$

Owing to the expression of the gas pressure $P_g = \frac{\mathscr{R}}{\mu}\rho T$ and the relation $\frac{dT}{dr} < 0$ in the region of radiation eqilibrium, one obtains from Eq. (7)

$$\frac{d\rho}{dr} > 0. \tag{8}$$

From Eq. (8) we know that the density gradient must reverse in the dynamical instable region.

According to the mentioned-above discussion a criterion for the occurrence of dynamical instability in the convective envelope is obtained as follows: The dynamical instability occurs when the function $\Gamma_g \equiv \frac{g_R+g_t-g}{g} > 0$, and the density gragient reverses $\frac{d\rho}{dr} > 0$.

3. The mechanism powering mass ejection

In order to investigate whether the dynamical instability can occur in the regions close to the surfaces of red giants and AGB stars, we perform the evolutionary calculations for the stars of $7M_\odot$ and $2.8M_\odot$ from the zero-age main sequence to the AGB stage taking into account of turbulent pressure. The numerical model and the expressions for turbulent pressure,the equation of state and the thermodynamical quantities with the consideration of turbulent pressure are discussed in detail in the first paper of this series (cf.Jiang and Huang 1996). The variations of the density and the function Γ_g in the envelope of the star of $7M_\odot$ during the AGB stage are illustrated in Fig. 1. The solid

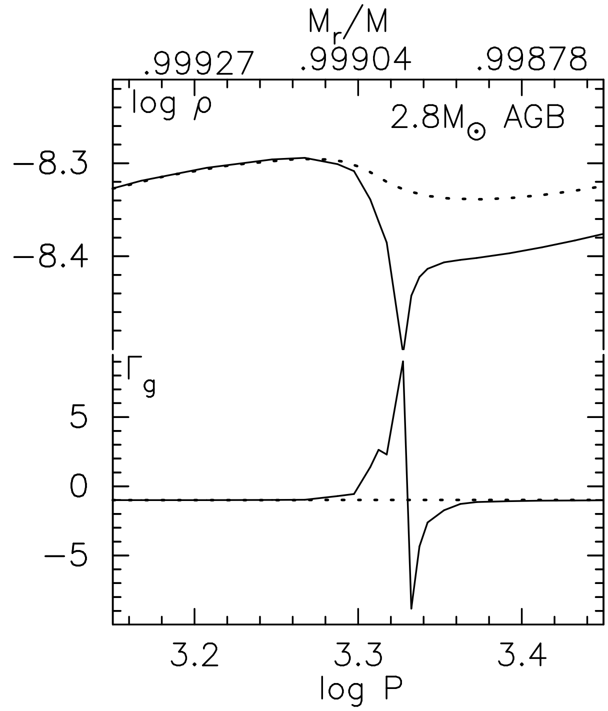

Fig. 3. The changes in the density ρ and the value of Γ_g in the envelope of an AGB star of $2.8 M_\odot$. The solid and the dotted curves have the same meaning as in Fig. 1.

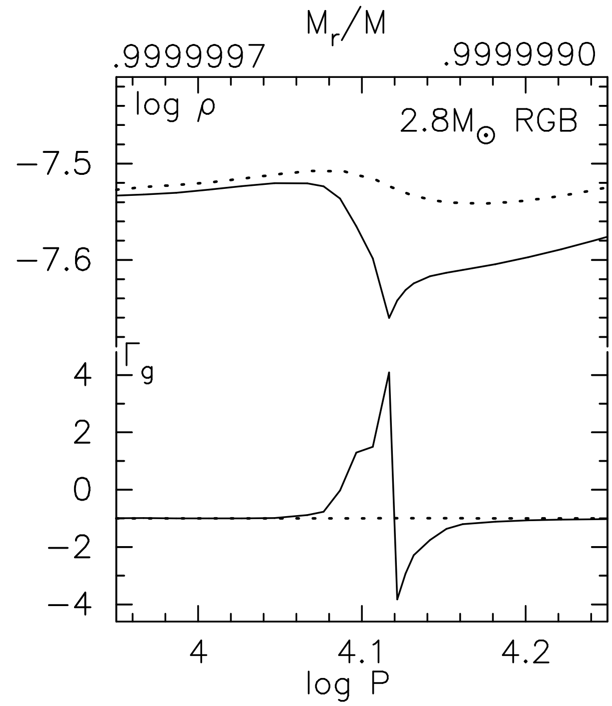

Fig. 4. The changes in the density ρ and the value of Γ_g in the envelope of a red giant with $2.8 M_\odot$. The solid and the dotted curves have the same meaning as in Fig. 1.

and the dotted curves in Fig. 1 (also in all the following figures) indicate the cases with or without the contribution of turbulent pressure, respectively. From the solid curves in Fig. 1 we find that in the region where the relative mass M_r/M has the values of 0.992-0.993 the value of the function Γ_g is positive ($\Gamma_g > 0$) and the desity gradient reverses ($\frac{d\rho}{dr} > 0$). This indicates that this region is dynamically instable when the contribution of turbulent pressure is considered. However, the dotted curves in Fig. 1 show that in the same region the value of the function Γ_g is negative. This means that the same region is stable when the contribution of turbulent pressure is neglected. Therefore, the occurrence of dynamical instability in the region with $M_r/M = 0.992 - 0.993$ of the AGB star of $7M_\odot$ is caused obviously by the effect of turbulent pressure. Furthermore, the solid curves in Fig. 1 show that in the layers outside the instable region the value of the function Γ_g is negative. This indicates that these layers are in the hydrostatic equilibrium. As a result of the fact, the gas elements in the instable region move outwards but the gas elements in the layers outside the instable region are quite, a shockwave might occur on the outer border of the instable region.The shockwave finally induces mass ejection of the outer layers. This might be the mechanism powering the superwind of the AGB stars. The variations of the density ρ and the function Γ_g in the envelope of the star of $7M_\odot$ during the red giant stage are illustrated in Fig. 2, where the curves have the same behaviour as shown in Fig. 1. Thus, we know that the effect of turbulent pressure causes the dynamical instability in the region which has the relative masses of 0.99996-0.99997. As a result, a mass ejection occurs at the surface of the red giant of $7M_\odot$ due to the same mechanism as described above. Comparing the position of the instable region in Fig. 1 to that in Fig. 2, we find that the position of the instable region for the AGB star of $7M_\odot$ is deeper than that for the red giant of $7M_\odot$. This indicates that the rate of mass loss of the AGB star must be greater than that of the red giant with the same initial mass. Figs. 3 and 4 show the variations of the density ρ and the function Γ_g in the envelopes of the star of $2.8M_\odot$ during the AGB stage and the red giant stage respectively. The curves in Figs. 3 and 4 have the same character as shown in Figs. 1 and 2. Thus, we know that the effect of turbulent pressure also causes the dynamical instability in the regions close to the surfaces of these stars. As a result the mass ejection occurs at the surface of the star of $2.8M_\odot$ during the AGB stage and the red giant stage.

Acknowledgements. This research is suppoted by the National Natural Science Foundation of China.

References

Castor J.I., 1981, in: Iben i., Renzini H (eds.) Physical Processes in Red Giants, Reidel, Dordrecht, p. 285

Feast M.W., 1992, in: de Jager C., Nieuwenhuijzen H. (eds.) Instabilities in Evolved Super- and Hypergiant. Amsterdam, North- Holland, p. 18

Han Z., Podsiadlowski Ph., Eggleton P.P., 1994, MNRAS 270, 121
De Jager C., Nieuwenhuijzen H., 1988, in: Nomoto K. (ed.) Atmospheric Diagnostics of Stellar Evolution, Lecture Notes in Physics, Vol.305, Springer-Verlag, p. 102
Jiang S.Y., Huang R.Q., 1996, A&A, in press
Lucy L.B., 1967, AJ, 72, 813
Paczynski B., Ziolkowski J., 1968, Acta.Astron. 18, 255
Renzini A., 1981, in: Chiosi C., Stalio R. (eds.) Effects of Mass Loss on Stellar Evolution, IAU Coll. No.59, Reidel, Dordrecht, p. 319
Tuchman Y., Sack N., Barkat Z., 1979, APJ 234, 217
Vassiliadis E., Wood P.R., 1992, Proc.ASA 10 (1), 30
Wannier P.G., 1984, in: Araki H., Ehlers J., Heep K., Kippenhahn R., Weidenmuller H.A., Wess J., Zittarz J. (eds.) Cool Stars, Stellar Systems, and the Sun. Springer-Verlag, p. 296
Willson L.A., Hill S.J., 1979, APJ 228, 854
Willson L.A., Kowalsky P., 1987, in: Kwok S., Pottash S.R. (eds.) Late Stages of Stellar Evolution. Reidel, Dordrecht, p. 277
Wood P.R., 1974, APJ 190, 609
Wood P.R., 1979, APJ 227, 220
Wood P.R., 1981, in: Iben I., Renzine A. (eds.) Physical Processes in Red Giants, Reidel, Dordrecht, p. 135
Wood P.R., Bessell M.S., Fox M.W., 1983, APJ 272, 99
Wood P.R., Vassiliadis E., 1992, in: Bergson J. (ed.) Highlights of Astronomy, Vol.9, p. 167

This article was processed by the author using Springer-Verlag TEX A&A macro package version 4.