ON THE EXISTENCE OF HOT CORONAE IN HOT STAR WINDS

Jean-Pierre J. LAFON
Observatoire de Meudon
Département Recherches Spatiales
92190 - Meudon (France)

It is now well known that early type stars, like O and B stars, loose mass at a very high rate (10^{-6}-10^{-5} M_0/yr). Besides, observed P-Cygni line profiles in ultrviolet radiation indicate that the outer layers of their extended atmospheres are moving with large expansion velocities (600-3000 Km/s). Both phenomena seem to occur under the form of rather steady state regimes, at least for O and B type stars. This communication is concerned with the mechanism which produces the motion of the matter.

This mechanism is far from being cleared up. It is established that Parker's (1958) mechanism, i.e. The thermal expansion of a gravitating gas in a vacuum in the case where the force due to the thermal pressure can exceed gravity is not sufficient in this case: even if the total thermal energy was converted into kinetic energy, expansion velocities could be of the observed order of magnitude only for coronal temperatures like 10^7 °K, for which the observed ions (CIV, NV, SiIV) would be destroyed by collisional ionisation. Now, since the stars under consideration are very luminous, one can think that the radiative pressure is active and drives the wind. Of course, this is the basic assumption of papers dealing with models of dynamically consistent winds for hot stars (Lucy and Solomon, 1970; Castor, Abbot and Klein, 1975). In such an approach of the problem the equations describing the radiative transfer and the statistical equilibrium must be solved together with equations describing dynamics: this is a formidable numerical problem which, for time being, cannot be solved without rather crude approximations.

The models are based on the usual assumptions concerning no time dependance (steady state) and spherical symmetry (rotation and magnetic field are assumed negligible so far as the dynamics of the wind is concerned). Radiative equilibrium is also assumed throughout the extended atmosphere. The equations solved are those describing mass conservation and momentum transport, assuming that the whole momentum supplied to the highly ionised atoms (carbon, oxygen ...) is transmitted by strong collisions to the protons which, with electrons, are the major components of the extended atmosphere.

The differences come mainly from the computation of the radiative force appearing in the equation describing the momentum transport. The main drawback of the most sophisticated model (Castor, Abbot and Klein, 1975) is that the radiative force is estimated as a purely local function of the velocity gradient ($\sim (dv/dr)^{\alpha}$) based on Sobolev's approximation (large velocity gradients) throughout the extended atmosphere.

First, concerning physics, this assumption is not reliable for all radial distances for which it should be. Indeed, the condition that the solution is required to satisfy in the outer part of the wind expresses the existence of non negligible thermal effects in the wind at large radial distances of the order of 10^4 stellar radii. Thus, the mathematical expression of the radiative force should be a good approximation up to such radial distances at least. However, because of the decrease of the velocity gradient (the velocity tends to the terminal velocity) Sobolev's approximation breaks for radial distances much smaller than 10^3 stellar radii (Leroy and Lafon, 1980a). Moreover, for radial distances of the order of 10^4 stellar radii the wind is very tenuous and its interaction with the surrounding medium should be taken into account, so that a condition derived from the only physics of a spherically symmetric expanding atmosphere is probably irrelevant (for instance the spherical symmetry may be upset, the ionisation may be changed ...).

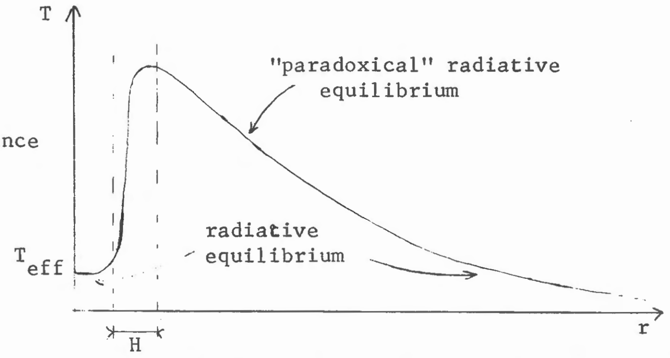
On the other hand, the assumption could be allowable only if the processes governing the wind structure were active mainly in the supersonic part of the wind (out of which Sobolev's approximation breaks) and if those active in the subsonic part of the wind were much less important and could be described very crudely. Now, using a new model based on a full solution of a simplified transfer equation (continuum + lines modelized with a picket-fence model), Leroy and Lafon (1980b) solved the coupled radiative and hydrodynamical equations simultaneously. They did not get rid of the strongly non local nature of the radiative transfer and did not neglect the inner boundary conditions concerning radiation (thermalization): the results show that these two phenomena are very important and, through the way in which the radiative force increases at the base of the wind, govern the mass loss and the terminal velocity. Besides it was noted that thermal effects at large distances produce weak effects and cannot be crucial for the topology of the density and velocity profiles.

Then, from a mathematical point of view, the expression of the radiative force as a function of the radial distance, the local velocity gradient, the whole velocity profile throughout the extended atmosphere is crucial for the existence, thenature, the location of a critical point for the velocity profile. For instance, if one expresses the radiative force as a function of the only local velocity gradient, one finds a critical point different in nature from that of Parker's type solutions and distinct from the sonic point at which the velocity reaches the thermal velocity (Castor Abbot and Klein, 1975). This can alter in a non negligible way the structure of the solution and so the derived terminal velocity and mass loss rates (Leroy and Lafon, 1980a,b).

Finally, Leroy and Lafon (1980b) found that, for realistic star parameters like those of Zeta Puppis, driving forces taking into account the inner radiative boundary conditions and the non local properties of radiative transfer do not allow winds with both realistic terminal velocities and realistic mass loss rates. Roughly, the reason why this happens is that the radiative force increases with radial distance too slowly to become efficient as soon as the force due to the thermal pressure becomes small.

Thus, under the assumption of no additionnal heating, in the case where radiative equilibrium holds throughout the extended atmosphere, the radiative force seems not to be sufficient to drive the observed winds. One is lead to think that, in fact, the radiative equilibrium can be disrupted somewhere so that the temperature no longer decreases smoothly from the photosphere to infinity: in other words a hot corona may exist. Upon these grounds we can propose the following scheme illustrated by the figure:

The curve represents the temperature T as a function of the radial distance r. Close to the photosphere T is of the order of T_{eff}, the effective temperature. Farther, there is a thin region of width H where some energy is dissipated, leading to a high temperature like a coronal temperature. At larger r the



General scheme for energy balance

radiative equilibrium holds; thus there is a region in which the radiative equilibrium can be called "paradoxical" in the sense that the temperature can be large compared to the usual radiative equilibrium temperatures ($\lesssim T_{eff}$) because it has to fit in with that in the thin corona.

Assuming that the corona is heated by dissipation of acoustic waves, one can estimate thet H is of the order of 10^{-5} stellar radii, which is much smaller than the scale height of density ($\approx 10^{-3}$ stellar radii). Although this region is very thin it is large enough to account for the presence of highly ionized atoms such as OVI if produced by X-rays according to Cassinelli's and Olson's (1979) mechanism. Of course the corona may be heated by another (magnetic?) source of energy.

In any case, a localized dissipation of energy (the cause of which is to be found) in a very thin region may give rise to a thick hot region that can change strongly the dynamics and finally explain the observed winds.

REFERENCES

- Cassinelli J.P. and Olson G., Astrophys. J., 229, 1979, 304
- Castor J.I., Abbot D.C. and Klein R.I., Astrophys. J., 195, 1975, 157
- Leroy M. and Lafon J.-P.J., On the importance of boundary conditions and non local properties of radiative transfer coupled with hydrodynamics in hot star winds, 1980a
  Can hot star winds be driven by radiation pressure? I and II, 1980b
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- Parker E.N., Astrophys. J., 128, 1958, 664