PROPERTIES OF OPTICALLY THICK WINDS DRIVEN BY RADIATION PRESSURE

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ABSTRACT

Conditions are derived for supercritical winds, accelerated by the radiation pressure of an object above the Eddington limit. A relation between the different energy fluxes is found. The conditions seem to be satisfied by novae, and perhaps by η Car. They are not satisfied however by the symbiotic star Z And.

This text is a short summary of a paper which is being submitted for publication.

Continued ejection for novae was first suggested by Grotrian before the war. Supported by a number of observers, it was ignored by theoreticians for many years, but recently interest in this type of model has considerably increased. The possibility of a similar physics applying to other types of peculiar stars has also been raised.

A number of papers (Friedjung 1966, Bath and Shaviv 1976, Bath 1978, Ruggles and Bath 1979) have shown that the continued ejection of novae after maximum can be associated with an optically thick wind accelerated by radiation pressure. Such a mechanism has however a number of physical difficulties; the central object would have to radiate above the Eddington limit, and it is not easy to obtain a steady state solution under such conditions. However Ruggles and Bath (1979) have recently given steady state solutions for which a substantial part of the flux is advected by the high velocity gas. The diffused flux is below the Eddington limit below the critical point, and above the limit higher in the wind. The advected flux diffuses out at smaller optical depths. In the present study a relation concerning the ratio of radiative flux to the kinetic energy flux in the photosphere (where the optical depth of the wind is 2/3) is shown to exist for such solutions, if the object is significantly above the Eddington limit. An approximate relation between

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the terminal velocity, the luminosity and the photospheric radius is obtained.

In order to obtain these results, the acceleration dv/dr with respect to the log radius r below the photosphere is considered. When the acceleration due to gas pressure is small compared with that due to the radiation pressure,

$$\frac{1}{2}\frac{dv^2}{d(\ln r)} = \frac{G\,M}{r}\,(L/L_{ed} - 1) \tag{1}$$

Here M is the stellar mass, L the diffusive luminosity, and L_{ed} the Eddington limit luminosity. One sees that after acceleration mainly near a radius $r = r_{ac}$, the velocity becomes almost constant for larger radii, tending to $v = v_s$. Two conditions apply at $r = r_{ac}$:

(a) $$v_s/r_{ac} = dv/dr \tag{2}$$

Combined with a condition for the photospheric radius r_s of Ruggles and Bath, one obtains at $r = r_{ac}$:

$$r_{ac}/r_s = \frac{2\,\kappa_t}{a\,\bar{\kappa}}\left(\frac{L}{c}\,\frac{1}{\dot{m}\,v_s}\right) - \frac{G\,M}{v_s^2 r_s} \tag{3}$$

$\bar{\kappa}$ is the effective photospheric opacity of Ruggles and Bath, κ_t the total opacity, a is a constant near unity, and $\dot{m}$ is the mass loss rate.
(b) The advected flux $L^{adv} \cong L$ at $r = r_{ac}$. This is because as shown by Ruggles and Bath $L^{adv} \ll L$ in the photosphere, while L^{adv}/L increases inwards. When $L^{adv} > L$, the acceleration due to L as shown in equation (1) would be smaller generally than where $L^{adv} \cong L$ (if it is supposed that the velocity is still near v_s in such regions), as it can be readily shown that L would there tend to decrease with decreasing radius. Hence the acceleration to $v \cong v_s$ could not occur for radii smaller than where $L^{adv} \cong L$, reached at $r \cong r_{ac}$ for luminosities significantly above the Eddington limit. One then obtains,

$$1 \cong \frac{L^{adv}}{L} = 16/3\,\frac{v_{ac}}{c}\,\frac{r_{ac}^2}{r_s^2}\,\frac{P_{ra}}{P_{rs}} \tag{4}$$

where $v = v_{ac}$, slightly less than v_s at $r = r_{ac}$, the radiation pressure at $r = r_{ac}$ is P_{ra}, and that at $r = r_s$ is P_{rs}.

Equations (3) and (4) can be used to obtain a condition for objects significantly above the Eddington limit if κ_t is proportional to a power α of r for $r > r_{ac}$ ($\alpha = 1$ in the Thompson scattering case, which usually applies for novae):

$$\left(\frac{\kappa ts}{a\,\bar{\kappa}}\right) L - \frac{1}{2}\,\frac{c}{v_s}\,\frac{G\,M\,\dot{m}}{r_s}\,(r_{ac}/r_s)^{-\alpha} = 8/3\,\dot{m}\,v_s^2\,(v_{ac}/v_s) \tag{5}$$

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where $\varkappa_{ts}$ is $\varkappa_t$ at $r = r_s$. The first term is of the order of the radiative flux, the second of the order of the gravitational energy flux in the acceleration region, and the last term of the order of the kinetic energy flux. A final condition is found,

$$\varkappa_{ts} L - 4\pi(16/3)^{\frac{-\alpha}{1-\alpha}} G M c (v_{ac}/c)^{\frac{-\alpha}{1-\alpha}} = \frac{64}{3}\pi v_s^3 r_s \left(\frac{v_{ac}}{v_s}\right) \quad (6)$$

Well above the Eddington limit the gravitational flux term is significantly smaller than that of radiation, so an order of magnitude estimate can be obtained by dropping the second term on the left hand side of eq. (6). It is clear that if tested using observations, equation (6) is very sensitive to v_s, as its right hand side is proportional to v_s^3.

Old studies by the present author of various novae gave results which are consistent with the conditions of the present study. Better tests can be made for the novae FH Ser and V1668 Cyg, observed in the ultraviolet by satellites. The calculations for these novae indicate that the conditions are not violated, though a kinetic energy flux excess of an order of magnitude may be due to the approximate nature of the conditions.

Bath (1977) and (1979) suggested a similar mechanism for symbiotic stars and Hubble-Sandage variables, the energy coming from super critical accretion. The flux condition seems however to be violated by a factor 10^3 in the case of the symbiotic star Z And, and a smaller disagreement may exist for η Car, the latter probably being related to the Hubble-Sandage variables. However there is some uncertainty in the physical parameters for η Car, and the energy flux given by Andriesse et al. (1978) agrees with the present conditions. Thus unless stars like Z And are improbably close to the Eddington limit, they probably do not have optically thick winds accelerated by radiation pressure. Stars like η Car might however have such winds. This type of wind should therefore be taken into account for certain special objects.

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