MASS LOSS FROM ASTRONOMICAL OBJECTS; A SUMMARY

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ABSTRACT

In this summary of the Joint Discussion on mass loss I discuss successively:

(1) stellar mass loss data and possible mechanisms
(2) mass loss for special types of stars and suggestions for future research in the stellar case
(3) interaction with the interstellar medium
(4) mass loss from quasars

1. STELLAR MASS LOSS AND MECHANISMS

Figure 1 is a Hertzsprung-Russell diagram showing stellar rates of mass loss, and it shows that lines of equal average rates of mass loss are monotonous and continuous. This indicates that similar laws must apply to the mechanisms of mass loss from hot as well as from cool stars. This is an important conclusion since most authors believe so far that the mechanisms of mass loss are different for these two groups of stars. The diagram also shows that for the same bolometric luminosity the mass loss is larger for cool stars than for hot ones, which shows that radiation pressure is most probably not the dominant mechanism. Indeed, one should look for a mechanism that predicts a rate of mass loss increasing with decreasing effective temperature. Finally, the diagram shows that there are a few groups of stars with rates of mass loss greatly exceeding the average value that would be obtained by interpolation from data for other stars; we will refer to this matter in Section 2.

Before discussing the problem of the mechanism it should be repeated here that the conventional Parker theory, or any modern version of it, can only yield the velocity law v(r) since in its derivation only dynamical terms enter through the equations of conservation of mass and momentum. In order to know the rate of mass loss $\dot{M}$ the energy equation should be included too. Earlier (De Jager, 1982) I have compared this

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problem with that of a river and its glacier: knowledge of the slope of the river bed and of the acceleration of gravity can only yield the velocity of streaming (for weak currents), but in order to know the mass flow the heat absorbed by the glacier should be known. Hence, the main problem is to find the energy term, responsible for the rate of mass loss. It will be of a MHD character when magnetic fields are important.

In his talk Lucy, dealing with hot stars, gave arguments that fluctuations in the winds of such stars tend to be sustained, thus maintaining highly supersonic shocks. He forwarded the hypothesis that a shock model of the stellar winds might explain the observed X-ray spectrum of O- and B-type stars. The semi-quantative model proposed by him does however contain adjustable parameters, so that the quantitative agreement found between theory and observations is not yet convincing; it is however an interesting first step into a promising field of research.

It is not certain that the same mechanism applies to cool stars. Hartman assumed, as is conventionally done, that the coronae and winds of these stars are related to mechanical heating. Since, as in the case of the Sun, magnetic fields of the stellar active regions will be important the heating mechanism and the winds will be magneto-hydrodynamic in character. The rate of mass loss will be related to the rate of energy dissipated. This rate may be important in certain cases, as is shown by the large 'turbulent' or wave-like motions in the atmospheres of some stars, as appears from the observation of the profiles of the C III 1909 Å line. The mathematical formalism for the velocity law can be established and includes a magnetic term. But also here, the essential problems how the energy is dissipated and how to explain the observed rate of mass loss have not yet been answered satisfactorily.

2. SOME SPECIAL TYPES OF STARS

The rate of mass loss of *Wolf-Rayet stars* is about ten times the value that would be expected from interpolation of data for 'normal' stars, as is shown by Figure 1. That they must have a large rate of mass loss was expected already for a long time and is evident from a comparison of their spectra (typical for dense, rapidly expanding atmospheres) with those of other stars with the same effective temperatures and gravity values. McCray mentioned that some WR stars appear to be surrounded by a ring nebula, the mass of which can be determined. In some cases one can be fairly certain that virtually this whole mass must have been expelled by the star (no swept up interstellar gas), and hence the original mass of the star can be determined. One wonders, however, whether this is also valid in the special case of a ring with a mass of 400 $M_\odot$! These few cases of very large masses are associated with luminous WR stars that have strong stellar winds. But in most cases the mass loss is of the order of 10 to 20 $M_\odot$, suggesting initial masses of 20 to 40 $M_\odot$. This approach may be a new and promising way to determine the ZAMS mass of a WR star, a fundamental quantity for Wolf-Rayet evolution theory.

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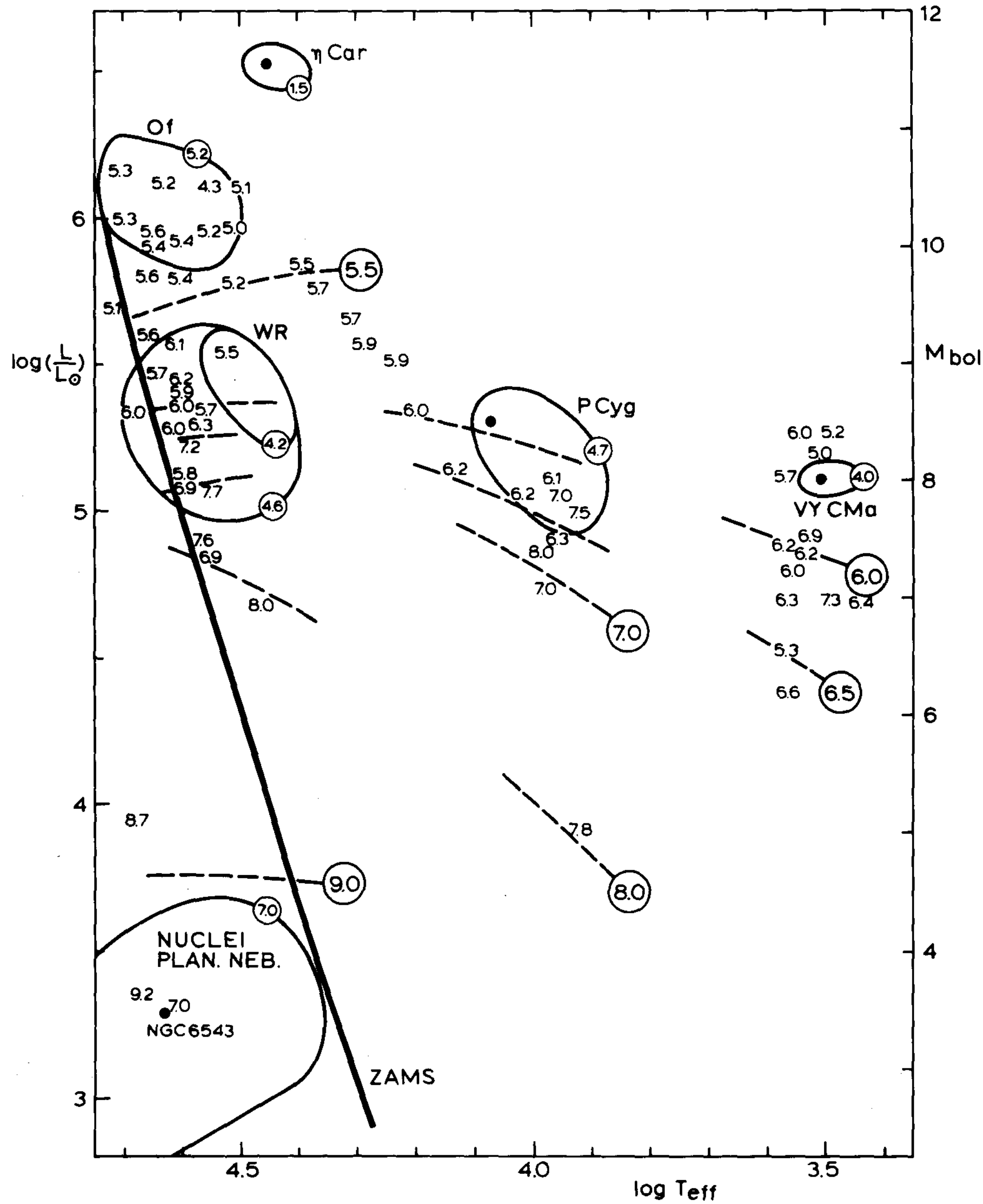

Figure 1. Review of mass loss values in the upper part of the Hertzsprung-Russell diagram. Data for individual stars are shown by the values of - log $(-\dot{M})$ $[M_\odot\ y^{-1}]$*. Lines of equal mass loss rates are labeled by their logarithmic values. Groups of stars or individual objects with greatly deviating values are encircled. The dots refer to the positions of η Car, P Cyg, VY CMa and the central star of NGC6543.*

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The *novae* are with the Be stars the only classes of stars for which there is clear evidence for non-radial emission of matter. Gas seems to be emitted in equatorial rings and in polar caps. In his talk Friedjung showed a fine example of a P Cyg profile in a nova spectrum.

The interpretation of *supernova spectra* has been enigmatic for a long time because of the width of the lines, while it was unclear whether the lines are displaced and whether they are emission or absorption lines. Some clarity in these matters has been achieved with the help of ultraviolet spectral observations which showed that the strong ultraviolet resonance lines are undisplaced emission lines (the 'chromosphere') while the photospheric lines are mostly broad absorption lines, originating from the 'photosphere'. This interpretation allows for a better determination of mass loss data.

3. INTERACTION WITH INTERSTELLAR MATTER

The importance of the work reported by McCray is his attempt to set up a shock model for the interaction of a stellar wind with the interstellar gas, analogous to Sedov's earlier approach for supernovae. The difference between the two approaches is apparently that the one is dealing with instantaneous mass loss (supernovae), and the other with (assumed) continuous mass loss. Interesting is that the calculated total kinetic energy put into the interstellar medium by a stellar wind is of the same order of magnitude as that of supernovae of types I or II, so that stellar winds may appear to be important contributors to the energy balance of the interstellar medium. 'Interstellar bubbles' may originate, somewhat comparable to the supernova remnants. From some of these X-radiation might be detectable.

4. QUASARS

The primary question is whether one sees direct outflow of matter or internal gas motions. Line profiles in the optical spectral range and the continuous radio spectrum show that the first of these two alternatives is true. Assuming electron scattering driven outflow, functions like n(r), T(r) can be determined observationally. It is found that at $r \approx 4$ kpc the winds have supersonic speeds ($v \approx 10^3$ km s^{-1}), while $T \approx 10^4$ K. The mass loss amounts to about 0.1 $M_\odot$ yr^{-1}.

REFERENCE

De Jager, C.: 1982, *Mass Loss from Massive Stars*, in S. d'Odorico (ed): *The Most Massive Stars*, ESO Workshop, Garching, p. 67.

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