MASS LOSS FROM HIGHLY EVOLVED STARS

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1. INTRODUCTION

This is a summarizing discussion about detailed studies of stellar winds from hot,subluminous stars of different classes: two sdO's (Hamann et al.,1981), three extreme helium stars (Hamann et al.,1982) and one CPN (Hamann et al.,1983). All program stars have been analyzed previously in Kiel by non-LTE techniques with respect to effective temperature, gravity and abundances. For comparison, we have also included the Of-supergiant ζ Pup and the B-main sequence star τ Sco, because their winds have been investigated in detail by the same methods as applied in this paper (Hamann, 1980, 1981).

2. THE METHOD

The observational material for the mass-loss studies consists of IUE spectra in the high-dispersion mode. Those of the UV-resonance lines which indicate stellar winds are fitted with theoretical profiles.The line formation is calculated with the comoving-frame technique,assuming pure scattering by two-level atoms. The overlap of the doublet components is taken into account, and the photospheric contribution is also included if necessary.An example of a line fit is given in Fig. 1.

Only a lower limit of the mass loss rate can be deduced from the line fit, unless the ionization fraction of the considered ion is known. We also calculated theoretical ionization fractions,but because of the "superionization" of these stellar winds the calculations have free parameters.Only in some cases restrictions of the ionization fractions are obtained from theory.Often an upper limit of the mass loss rate is set only by the fact that the photosphere appears to be static. Generally, all mass loss rates derived from UV lines suffer from the great uncertainties in the ionization fractions.

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3. RESULTS AND DISCUSSION

Principally, we find that the wind parameters derived for these subluminous stars fit well into the general picture of stellar winds from early-type stars. Is there a general formula, predicting the mass loss rate of a star when certain parameters are given? Our program stars, together with the (commonly studied) OB supergiants, provide a wide range of stellar parameters and hence an improved basis to discuss this question. Fig.2a gives the empirical mass loss rates versus luminosity. ζ Pup and the subluminous stars can be related by $\dot{M} \propto L^{1.5}$. However, the scatter around this relation is probably larger than the errors in the data: τ Sco lies below it, and the three extreme helium stars have similar L, but very different mass loss. A better alignment is achieved in Fig.2b with the Reimers formula $\dot{M} \propto LR/M$, which was established originally for red giants and calibrated, e.g., with Antares (Kudritzki and Reimers, 1978). A similar relation was confirmed empirically for massive OB stars (Lamers, 1981). ζ Pup lies above the predictions of this formula by one order-of-magnitude, but τ Sco fits well. For our three helium stars, the R/M-dependance goes into the wrong direction.

The radiation-driven wind theory (Castor et al., 1975) predicts the mass flux (per surface unit) in terms of effective temperature and gravity. Comparison with our program stars reveals poor agreement, which cannot be demonstrated here for sake of brevity.

Towards luminosities below 100 $L_\odot$, a strong constraint on the mass loss comes from the existence of helium-deficient OB subdwarfs. Even under optimum conditions, helium depletion by gravitational settling can only be efficient if the mass loss rate is smaller than predicted from extrapolation of Reimers' formula by at least a factor of 1000.

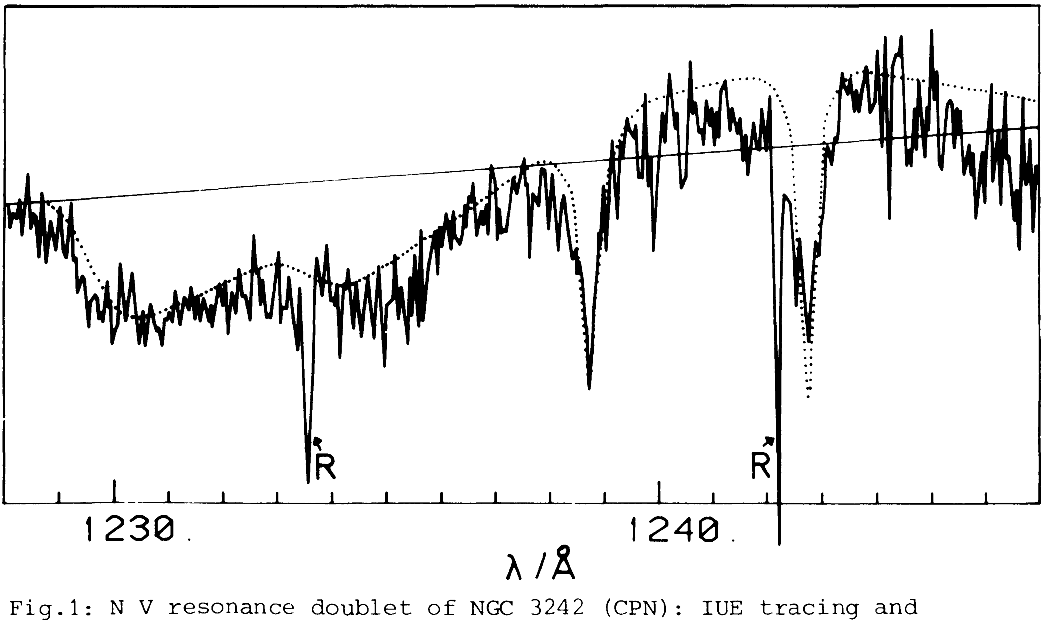

Fig.1: N V resonance doublet of NGC 3242 (CPN): IUE tracing and theoretical profile (dotted), R = reseau mark

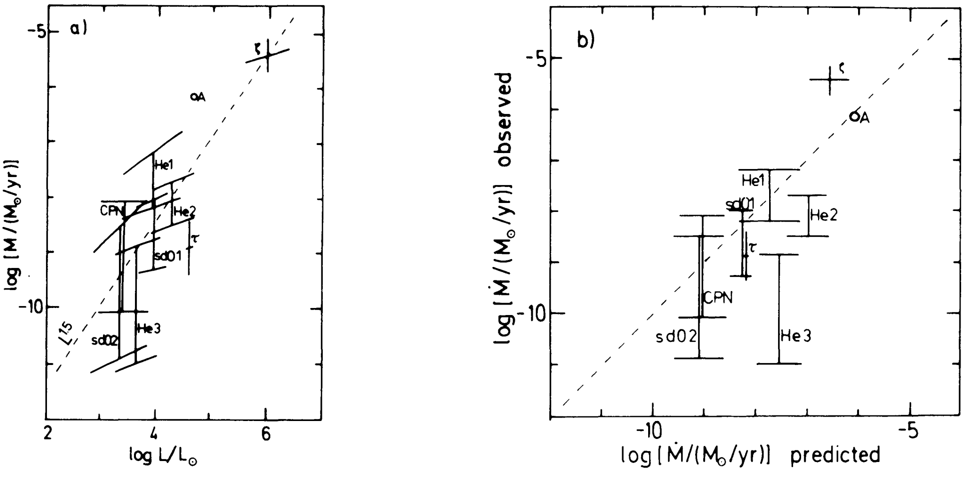

Fig.2: Empirical mass loss rates versus stellar parameters.
O-subdwarfs: sdO1 = HD 49798, sdO2 = HD 128220;
extreme helium stars: He1 = HD 160641, He2 = BD $-9^{o}4395$,
He3 = BD $+10^{o}2179$;
Central Star: CPN = NGC 3242;
comparison stars: ζ = ζ Pup (OfI), τ = τ Sco (BOV), A = Antares
a) $\dot{M}$ versus L b) $\dot{M}$ versus prediction of Reimers' formula

4. CONCLUSIONS

The Reimers-formula agrees with most observed mass loss rates within one order-of-magnitude. This holds for the subluminous stars studied here, as well as for the luminous (massive) OB stars and the red giants. Some stars behave peculiar, e.g. Of stars, Wolf-Rayet stars, extreme helium stars. An extrapolation of the mass loss prediction down to 100 $L_{\odot}$ is possibly prohibited.

5. REFERENCES

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DISCUSSION

Walborn: τ Sco has a very peculiar UV spectrum showing an enhanced stellar wind relative to normal stars of similar spectral types. A stronger mass or temperature dependence of mass loss along the main sequence than the relation you showed may be indicated.

Hamann: Yes, possibly. The problem is that only τ Sco has been studied in detail. From an only qualitative comparison of the spectral wind-features, one cannot distinguish whether the mass loss rates are different or the ionization conditions are not the same.

Richer: Just a comment. The few red giants that do have well determined mass loss rates (e.g. α Sco) have mass loss rates that are higher than Reimers by up to 3 orders of magnitude.

Conti: I'd like to comment on your presentation of the relation between $\dot{M}$ and L, along with such other parameters as M, R, T_{eff}, gravity. Dr. Garmany and I have just completed an analysis of some 50 O-type stars with systematic spectroscopy. We too find that $\dot{M}$ depends on L with an exponent of order 1.6. There remains considerable scatter. The scatter is reduced by parameterizing the M, R, T_{eff}, gravity in various combinations, but we cannot unequivocally determine the correct parameterization - some scatter still remains. It will be interesting to now compare our data since your objects have much smaller masses and radii.

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