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Radiation-driven winds of hot luminous stars

X. The determination of stellar masses, radii and distances from terminal velocities and mass-loss rates*

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Abstract. A new, purely spectroscopic method to determine masses, radii and distances of massive, luminous hot stars is presented. This method is based on the theory of radiation-driven winds and uses terminal velocity, mass-loss rate and effective temperature as observational quantities determined from the spectrum.

It is demonstrated that in situations where the distance is already known from other methods, masses can be determined from v_∞ and $T_{\rm eff}$ with an accuracy of $\pm 25\%$, which is a factor of two better than the classical method using the information obtainable from the quantitative analysis of photospheric absorption lines. These masses, which agree with those obtained from the spectroscopic values of $\log g$, are systematically somewhat smaller than masses found from evolutionary calculations.

An independent determination of radii and distances is possible, if good meaurements of mass-loss rates can be carried out. For two examples, ζ Puppis and P Cygni, it is shown that in such cases radii can be determined to an accuracy of $\pm 25\%$. This would transform into an uncertainty in distance modulus of $\Delta m_v = \pm 0.5$ mag for an individual object.

The potential of this method is discussed.

Key words: atmospheres of hot stars – stellar winds – stellar masses – stellar radii – stellar distances

1. Introduction

It is the dream of every stellar astronomer to be able to determine the mass, radius and distance of a normal single star directly from the observed spectrum by purely spectroscopic methods. As is well known, this dream has so far remained unfulfilled. The basic reason for this is obvious: photospheres of stars usually have a negligible extension compared with the stellar radius. Therefore, photospheric spectroscopy cannot provide knowledge about atmospheric or stellar dimensions but can only (beside abundances) yield information about temperature and density, which are normally parameterized in terms of the effective temperature $T_{\rm eff}$ and gravity $\log g$. Information about the stellar radius and, as a consequence, stellar mass and luminosity has to come from elsewhere, for instance from independent distance determinations or stellar evolution theory.

The situation changes if a star is surrounded by an extended stellar wind. The spectral lines formed in such a wind must, in principle, contain information about the geometrical extension, provided that we have a theory that describes the density, velocity and temperature stratifications as a function of stellar parameters with sufficient accuracy. For hot luminous stars, this theory could be that of radiation-driven winds.

This combination of photospheric and wind theory was first worked out by Kudritzki & Hummer (1986), who derived distances to four stars using their observed terminal velocities; they had also formulated the equations for the use of the mass-loss rate for this purpose. Ebbetts & Savage (1982) had used an empirical constant ratio between the terminal and escape velocities for the same purpose.

In this paper, we investigate whether the information about the terminal velocity v_∞ and mass-loss rate $\dot M$ obtained directly from the spectra of hot stars can, in practice, be used as a tool for the determination of stellar masses, radii (distances), and luminosities. The basis for this investigation will be the theory of radiation-driven winds as developed in the earlier papers of this series (for references, see below).

2. The concept

As shown by Kudritzki et al. (1989a, Paper VI) in their analytical treatment of wind theory including the finite cone angle effect, v_∞ and $\dot M$ can be expressed as functions of stellar temperature $T_{\rm eff}$, mass M and radius R and the force multiplier parameters k, α, δ

$$v_\infty = f_1\,(T_{\rm eff}, M, R, k, \alpha, \delta)$$
$$\dot M = f_2\,(T_{\rm eff}, M, R, k, \alpha, \delta) \quad (1)$$

The force multiplier parameters are not free but also depend on the stellar parameters (see Kudritzki et al. 1987, Paper II; Pauldrach 1987, Paper III; Puls 1987, Paper IV; Pauldrach et al. 1988, Paper V; Pauldrach et al. 1990 Paper VII; Pauldrach & Puls 1990, Paper VIII). Since the determination of $T_{\rm eff}$ from the

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* Based on observations carried out at the European Southern Observatory, La Silla, Chile

photospheric lines is a well defined standard procedure (see Kudritzki & Hummer 1990), Eqs. (1) can be used to derive M and R, if v_∞ and $\dot{M}$ have been determined from the spectrum.

We will investigate this possibility in two steps. First, we will study the simpler case that the distance and, therefore, the radius is known from other methods and that only the mass has to be determined. Then, we will obtain the mass and radius simultaneously.

3. Stellar masses from v_∞

For the determination of stellar masses when the radius is known the use of the relation for v_∞ is more advantageous than the one for $\dot{M}$ for two reasons. The measurement of v_∞ from the UV spectrum, although not trivial (see Groenewegen et al. 1990; Howarth & Prinja 1989), is simpler and the dependence of v_∞ on M is stronger.

We demonstrate the method by means of four early O-stars with well observed v_∞ values and stellar parameters determined from photospheric NLTE spectral analysis: ζ Puppis, HD 93129A, HD 93250, HDE 303308. The observed stellar parameters are given in Table 1.

A brief comment regarding the stellar parameters of the three O3-stars is necessary. They have been analyzed quantitatively by Kudritzki (1980) and Simon et al. (1983). However, these analyses were based on photographic plates of III a J emulsion. We have, therefore, reobserved these objects using the ESO 3.6 m telescope with its Cassegrain–Echelle spectrograph (CASPEC) and a CCD detector. The instrument configuration and spectral range as well as the methods used to reduce the data were as described by Kudritzki et al. (1989b). Figure 1 shows the profiles of the strategic lines for the NLTE analysis compared with the profiles computed for the final model. The fits are generally reasonable.

Table 1. Stellar parameters $T_{\rm eff}$, $\log g$, $R/R_\odot$, $\log L/L_\odot$

	$T_{\rm eff}$ (10^3 K)	$\log g$ (cgs)	$R/R_\odot$	$\log L/L_\odot$
ζ Puppis	42 ± 1.0	3.5 ± 0.1	17 ± 3	5.90 ± 0.1
HD 93129A	$50.5\pm^{1.0}_{1.5}$	$3.75\pm^{0.01}_{0.05}$	20 ± 2	6.35 ± 0.1
HD 93250	51.0 ± 1.5	3.90 ± 0.10	18 ± 2	6.30 ± 0.1
HDE 303308	48.0 ± 1.5	3.90 ± 0.10	12 ± 1.5	5.85 ± 0.1
HD 93128	52.0 ± 1.5	3.90 ± 0.10	10 ± 1.5	5.80 ± 0.1

The stellar parameters for ζ Puppis are taken from Bohannan et al. (1990)

The discrepancies in the cores of Hγ, He II 4200 and 4542 are attributed to emission of the surrounding stellar wind (see also Gabler et al. 1989).

The radii for the O3-stars were obtained from the absolute magnitudes derived by Simon et al. (1983) and the NLTE model atmosphere fluxes using the procedure described by Kudritzki (1980).

The terminal velocities v_∞ were determined by fitting the detailed shape of the UV wind profiles using the radiative transfer codes developed in our group. The values derived here, which appear in Table 2, agree reasonably well with Groenewegen et al. (1989) and the values of "$v_{\rm black}$" by Howarth & Prinja (1989). For HD 93128 no UV spectrum that would allow the measurement of v_∞ is available. We include this star here only because its optical spectrum was also reanalyzed.

The force multiplier parameters used for the calculation of v_∞ are given in Table 3. The values of column A are representative for ζ Puppis (see Pauldrach 1987; Puls 1987). According to Paper

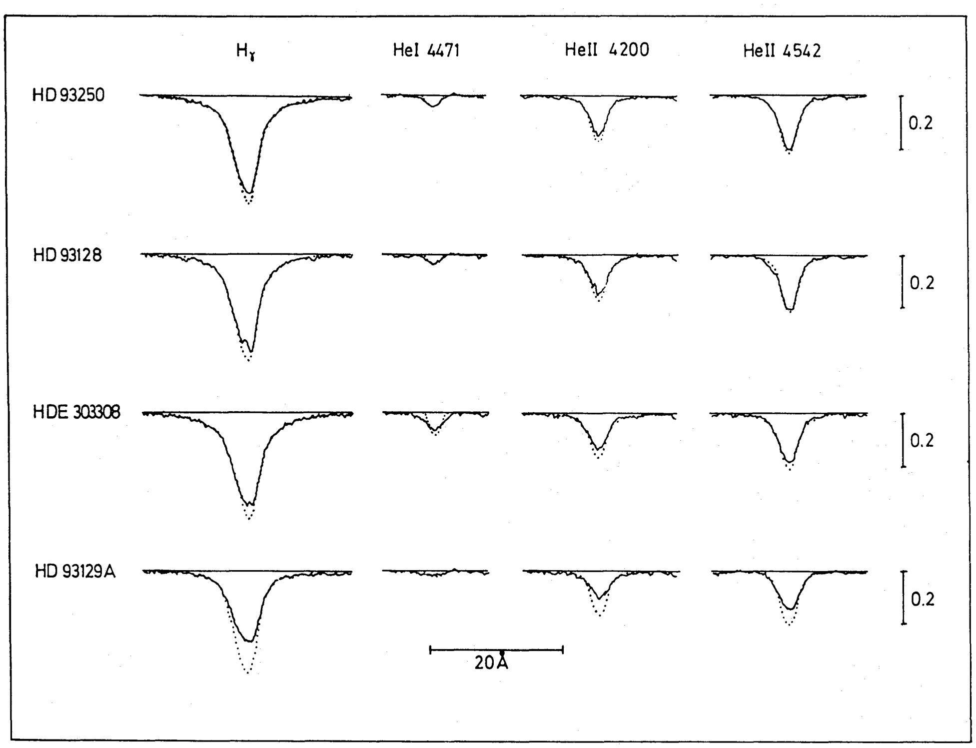

Fig. 1. Fit of the strategic hydrogen and helium lines of four Carina O3 stars by means of NLTE model atmospheres

Table 2. Terminal velocities

	GLP v_∞ (km s^{-1})	HP $v_{\rm black}$ (km s^{-1})	This work v_∞ (km s^{-1})
ζ Puppis	2200 ± 60	2485	2200 ± 100
HD 93129A	3050 ± 60	3150	3050 ± 100
HD 93250	3300 ± 200	—	3200 ± 100
HDE 303308	—	3035	3200 ± 100

GLP: Groenwegen et al. (1989); HP: Howarth & Prinja (1989)

Table 3. Adopted force multiplier parameters

	A	*B*
k	0.05	0.017
α	0.70	0.74
δ	0.05	0.115

VII they would also be appropriate for the O3-stars. However, very recent calculations including the EUV-radiation field of shocks (Pauldrach et al. in prep.) show that they must be modified for these very hot objects. The values of column B take this into account. For simplicity we use both sets A and B for each star to investigate the influence of k, α, δ on the mass determination.

The dependence of v_∞ on mass is displayed in Fig. 2. It is evident that a possible variation in k, α, δ has little impact on the determination of stellar masses. More important are the observational uncertainties of the stellar radii and temperatures that transform into the minimum and maximum values of the luminosities in Fig. 2. Adopting set A for ζ Puppis and set B for the O3-stars and taking into account the observed values for v_∞, we can derive masses. The results are given in Table 4.

Alternatively, the gravities determined from photospheric NLTE-spectroscopy together with the radii can also be used to obtain masses. The results are also to be found in Table 4.

The comparison of the v_∞ and $\log g$ masses indicates good agreement of these independent methods. However, the v_∞-method appears to be superior, because its uncertainties are smaller. For this method, only the uncertainties in the radius and temperature play a role, whereas the uncertainty of the v_∞ measurement is of minor importance. For the $\log g$-method uncertainties in both radius and $\log g$ contribute.

The third column of Table 4 gives masses derived from $T_{\rm eff}$ and $\log L/L_\odot$ using evolutionary tracks that evolve away from the ZAMS towards cooler temperatures (Maeder 1990). Strikingly, all masses determined in this way are systematically higher than those derived from v_∞ and $\log g$. This discrepancy has been found first by Groenewegen et al. (1989) and is confirmed by the recent quantitative spectroscopy of a large sample of galactic O-stars by Herrero and collaborators (Herrero et al. 1992). This means that either the masses determined by the two independent diagnostic methods (using v_∞ or $\log g$) are too low or that stellar evolution theory predicts masses too high for the observed luminosities. It is one of the challenges for the future

Table 4. Masses from v_∞ and $\log g$

	$\log M/M_\odot$		
	From v_∞	From $\log g$	From HRD and evolutionary tracks
ζ Puppis	1.58 ± 0.09	1.52 ± 0.2	1.77 ± 0.07
HD 93129A	1.96 ± 0.09	1.91 ± 0.2	2.09 ± 0.07
HD 93250	1.92 ± 0.09	1.97 ± 0.2	2.06 ± 0.07
HDE 303308	1.61 ± 0.08	1.62 ± 0.2	1.61 ± 0.07

work on massive stars to find the explanation for this discrepancy.

Independent of this indication of a possible systematic error in one of these methods, the mass determination using v_∞ appears, in principle, very promising. Provided that the stellar luminosities are known with an accuracy of ±0.1 dex (for instance, from cluster membership) the v_∞-method can yield masses with an accuracy of about 25%. Besides the mass determination in double-line eclipsing binaries this appears to be the most accurate method available for the direct determination of masses. It requires only the measurement of v_∞ from the UV spectrum and of $T_{\rm eff}$ from the optical spectrum.

4. Stellar masses and radii from v_∞ and $\dot{M}$

Now we assume that the stellar distances and radii are not known in advance and use both Eqs. (1) to determine mass and radius. As examples we have selected two stars with well observed mass-loss rates: ζ Puppis and P Cygni. Both objects are also interesting from an astronomical point of view. Such extreme supergiants are good candidates for detection by optical surveys in other galaxies.

We start with ζ Puppis. Its mass-loss rate can be determined in different ways, namely by UV resonance line fitting, by fiting of the Hα and He II 4686 emission lines or by fitting the far IR to radio energy distribution caused by the thermal free-free emission of the wind. In all cases $\dot{M}$ is not determined independently but in combination with the yet unknown stellar radius. In the case of UV resonance line fitting the run of Sobolev optical depth in the wind is determined. If v_∞ is known, this is proportional to

$$D_1 = \dot{M}/(R/R_\odot). \quad (2)$$

For the fitting of hydrogen and helium wind lines it is important to note that the corresponding occupation numbers are proportional to the square of the density ρ. In consequence, the strength of the wind contribution to Hα and He II 4686 depends on

$$D_2 = \dot{M}/(R/R_\odot)^{3/2}, \quad (3)$$

if v_∞ is known (see Leitherer 1988). Since the free-free absorption coefficient is also proportional to ρ^2, the strength of free-free emission of the wind depends on D_2 as well.

This means that, in principle, v_∞ and D_1 can be determined by UV-profile fitting while v_∞ and D_2 are obtainable if the information from the radio/FIR continuum or Hα/He II 4686 is used. We have, therefore, calculated v_∞, D_1, D_2 using the analytical approach of Paper VI (and force multiplier set A of Table 3) for a grid of models with $T_{\rm eff} = 42\,000$ K and masses and radii

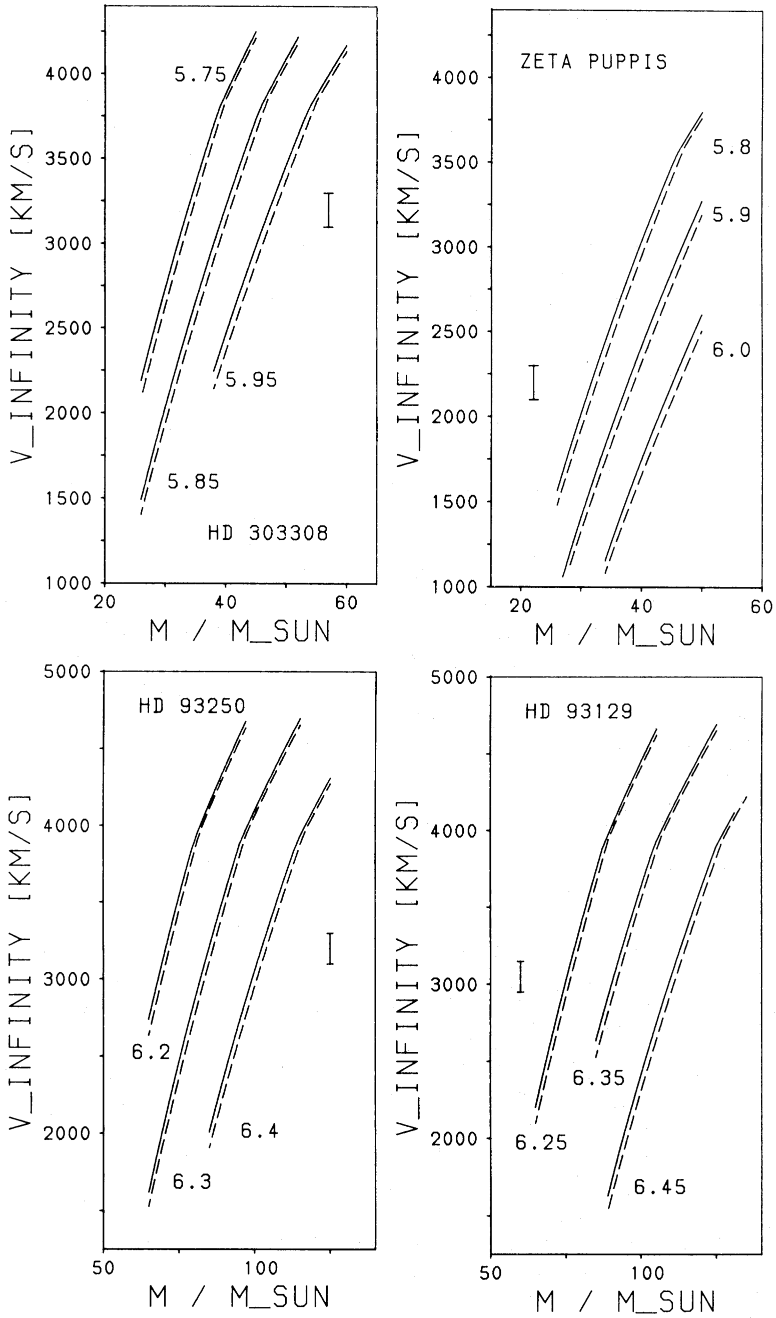

Fig. 2. v_∞ as a function of stellar mass for the four stars of Table 1. The solid and dashed curves refer to the force multiplier sets A and B, respectively. Each set of curves is labelled by the corresponding value of $\log L/L_\odot$. The observed v_∞ are indicated by a bar

varying between 9 to $230 M_\odot$ and 10 to $30 R_\odot$, respectively. The results are displayed in Figs. 3 and 4, where we have used $\log g$ as a parameter instead of M to allow a straightforward check of the consistency with the photospheric analysis. Obviously, if v_∞, D_1, D_2 have been measured from the observations with sufficient accuracy, an evaluation of radius and gravity (mass) should be possible.

Besides the measurement of v_∞ (see Table 2) the determination of D_2 from radio and far-IR fluxes is easiest and most accurate. Figure 5 shows calculations of the continuous energy distribution for a typical wind model with $v_\infty = 2200\,\mathrm{km\,s^{-1}}$, $R/R_\odot = 19$, $\dot{M} = 3\,10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$. From fits of this type we obtain $\log D_2 = -7.5$. The fit of the He II 4686 emission line using the "unifield model atmospheres" approach yields $\log D_2 = -7.3$ (see Gabler et al. 1990). To demonstrate our method we adopt

$$\log D_2 = -7.4 \pm 0.1 \tag{4}$$

for ζ Puppis. We note here that Gabler et al. obtained $\log D_2 = -7.1$ from Hα, with the corresponding He II blend included. We attribute this discrepancy to the fact that in the NLTE treatment of hydrogen and helium the direct radiative coupling due to neighbouring lines has been neglected so far.

With $\log D_2$ from (4) and v_∞ from Table 2 we obtain from Fig. 3 the following values for radius, gravity and mass:

$$R/R_\odot = 19 \pm 5$$

$$\log g = 3.55 \pm 0.05$$

$$\log M/M_\odot = 1.67 \pm^{0.15}_{0.22} \tag{5}$$

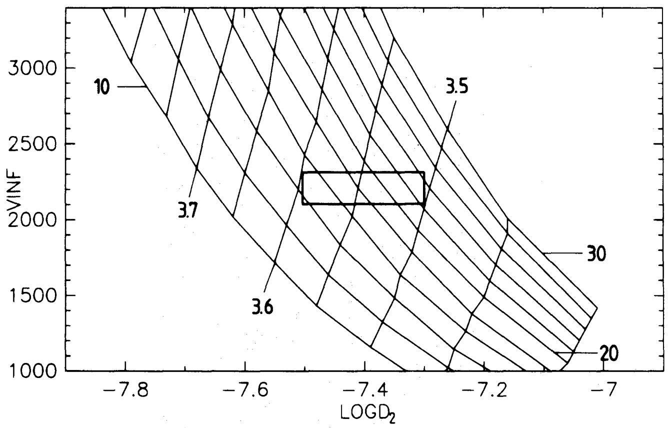

Fig. 3. v_∞ versus $\log D_2$ for a grid of models with different radii and masses with a fixed $T_{\rm eff}$ of 42 000 K. The force multiplier set A of Table 3 was used. Curves of constant $\log g$ and $R/R_\odot$ are labelled by their values. The rectangular box in the centre corresponds to the observations of ζ Pup

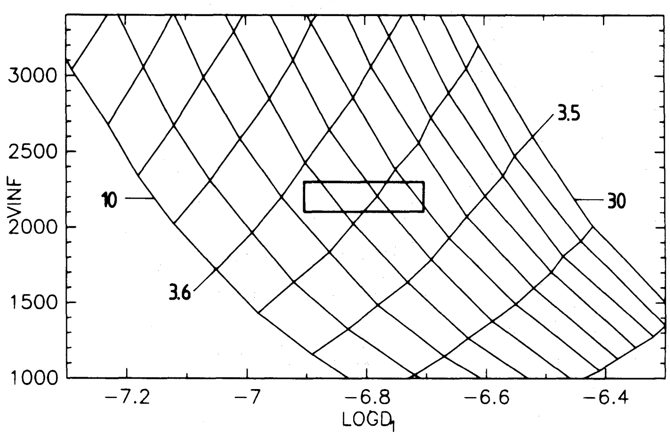

Fig. 4. Same as Fig. 3 but for $\log D_1$

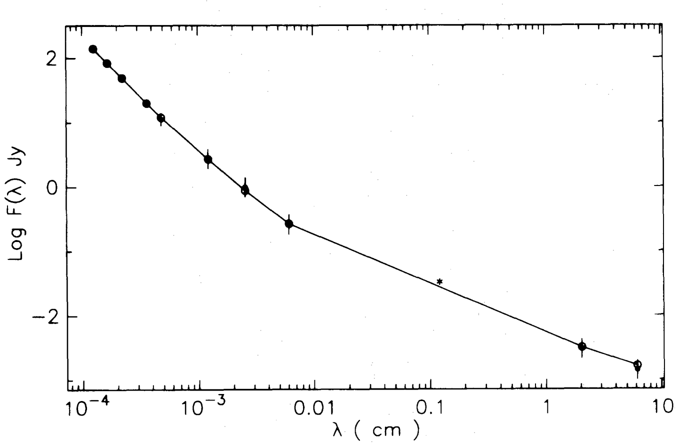

Fig. 5. The IR to radio continuum of ζ Puppis (filled circles and asterisk) compared with the radiation from a wind model with $v_\infty=2200$ km s^{-1}, $\dot M = 3\ 10^{-6}\,M_\odot$ yr^{-1}, $R/R_\odot=19$. The IR-observations are from Lamers et al. (1984), the radio data are from Abbott (1985) and Abbott et al. (1980). The asterisk corresponds to the mm-observation of Altenhoff et al. (1991) and is only an upper limit

This result requires several comments. First, we note that it agrees with that obtained by using photospheric spectroscopy together with the known distance. The uncertainties are, however, different. It is striking that the gravity obtainable from v_∞ and D_2 is more precise than the one from photospheric spectroscopy. The mass uncertainty is comparable to that normally obtained from the spectroscopic $\log g$ and known distance. However, in the current method the distance is not known in advance but is determined simultaneously. The radius determination appears to be quite uncertain. However, if we transform this into an uncertainty in the distance modulus via $\Delta(m_v - M_v) = 5\log(1+\Delta R/R)$, we obtain

$$\Delta(m_v - M_v) = \pm 0.5\ \text{mag} \tag{6}$$

For an individual distance determination of a single object this is promising.

The determination of mass and radius does, of course, depend on the force multipliers used. In particular, the parameter k that determines the strength of $\dot M$ is important. For ζ Puppis, all the NLTE wind calculations performed by our group up to now (including multi-line effects (Puls 1987) and the EUV radiation field of shocks, (Pauldrach et al. in preparation) lead to values of k that differ by not more than $\pm 10\%$. Diagrams similar to Fig. 3 for $k=0.055$ and 0.045 yield $R/R_\odot=16$ and 21, respectively. Changes in $T_{\rm eff}$ by ± 1000 K result in differences smaller than this. We therefore admit that the present uncertainties of wind theory could be the source of systematic errors of the order of 0.5 mag in the distance modulus for this new method. We feel, however, that this could be overcome by future improvements in the theory and a careful comparison with observations of a large sample of objects with well known distances.

An alternative to the use of D_2 as a mass-loss indicator would be D_1 as defined by Eq. (2), which is usually obtained by a fit of the UV resonance lines. Unfortunately, the fit of D_1 requires knowledge of abundances and degree of ionization for the individual ions. Following the great improvements in the theory in the past few years we are confident that in the near future it will be possible to determine these numbers reliably as well. Then, since many lines are observable in the UV, the use of D_1 might prove superior to D_2.

Figure 4 shows a diagram comparable to Fig. 3 but with $\log D_1$. If we suppose that an accuracy of 0.1 dex for $\log D_1$ would be achievable in the future then a value of -6.8 would give a radius of $R/R_\odot = 18\pm 3$ and a distance accuracy of $\Delta(m-M) = \pm 0.3$ mag.

Now we discuss the extreme B-supergiant and luminous blue variable P Cygni. Because of their extreme absolute magnitude ($M_v \approx -8.5$) and strong wind lines in the optical spectrum objects such as P Cygni are the luminous massive stars most likely to be detected in other galaxies. According to Lamers et al. (1985) the terminal velocity in the quiescent stages of P Cygni is 206 km s^{-1} with an uncertainty of 10%. We adopt

$$v_\infty = 210 \pm 20\ \text{km s}^{-1}. \tag{7}$$

$\operatorname{Log} D_2$ for the quiescent stage is again obtained from the IR radio energy distribution. Figure 6a shows that for $\log D_2 = -7.9$ a reasonable fit of the IR- and mm-observations is obtained, whereas the fit of the radio observations is marginal. The opposite situation occurs for $\log D_2 = -7.74$ (see Fig. 6b). We, therefore, adopt

$$\log D_2 = -7.8 \pm 0.1. \tag{8}$$

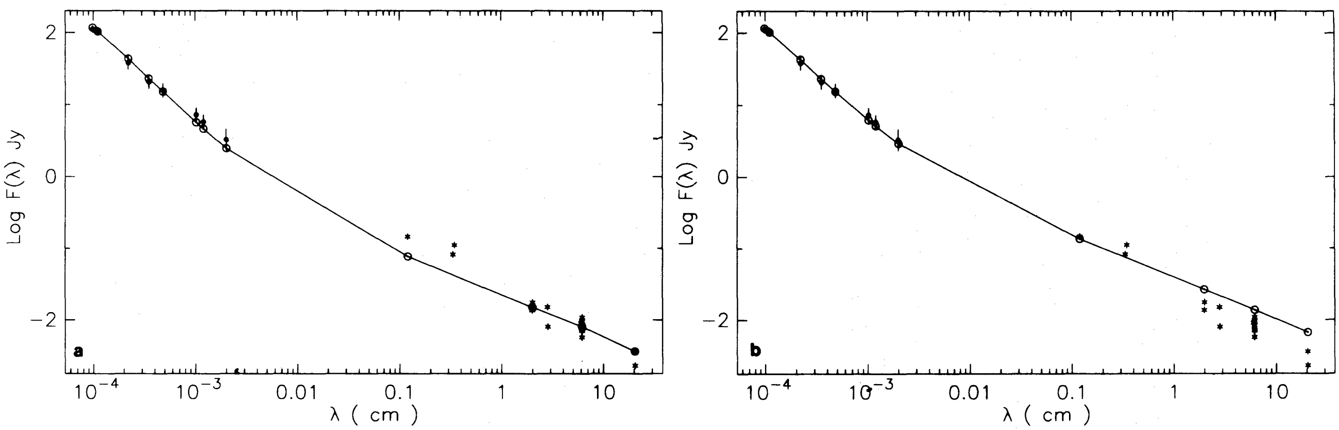

Fig. 6a and b. The IR to radio continuum of P Cygni (filled circles and asterisk) compared with radiative transfer calculations for the wind emission. **a** model with $R/R_\odot=76$ and $\dot{M}=8\,10^{-6}M_\odot\,\mathrm{yr}^{-1}$. **b** model with $R/R_\odot=76$ and $\dot{M}=1.2\,10^{-5}M_\odot\,\mathrm{yr}^{-1}$. The IR-data are taken from Abbott et al. (1984) and Waters et al. (1986). The radio observations are from Wendker (1987) (however, those labelled with "extended emission" have been neglected). The mm-observations are from Altenhoff et al. (1991)

For the wind calculations we follow Pauldrach & Puls (1990, Paper VIII), who have found from radiation driven wind models of P Cygni that the mass loss rate can switch between high and low values in response to very small changes in the stellar parameters arising from optical thickness effects in the Lyman continuum. We have, therefore, used three sets of force multiplier parameters (see Table 5 and Fig. 7) to describe the stages I, II, III of low, intermediate and high mass-loss, respectively. With these values and the analytical approach of Paper VI we are able to reproduce the calculations of Pauldrach and Puls (1990) including the multi-line effects on v_∞ (see their Sect. 4). Figure 8 shows the plot of v_∞ versus $\log D_2$ for P Cygni. From the comparison with the observed values we derive

$$R/R_\odot=75^{+10}_{-20},$$

$$\log g=2.05^{+0.04}_{-0.02},$$

$$\log M/M_\odot=1.36^{+0.09}_{-0.23}, \tag{9}$$

for radius, gravity and mass.

It is clear that a very precise determination of the gravity is possible. This is particularly important since the strong wind of P Cygni interferes with the usual method of photospheric spectroscopy for the determination of $\log g$. We see however, that the

Table 5. Force multiplier parameters for P Cygni (see also Fig. 7)

	k	α	δ
I	0.115	0.480	0.08
II	0.100	0.500	0.125
III	0.130	0.480	0.135

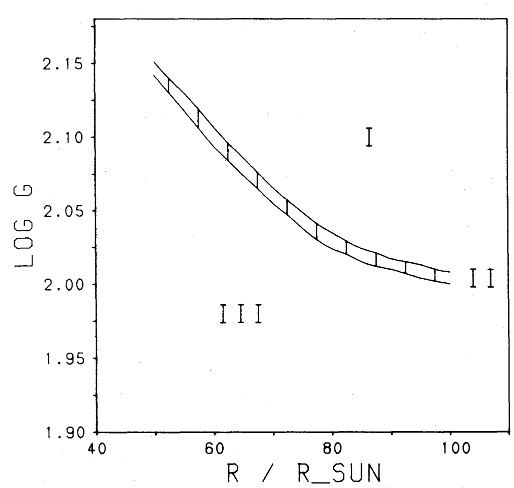

Fig. 7. The gravity and radius plane of stellar parameters for P Cygni showing the domains for the force multiplier sets I, II and III

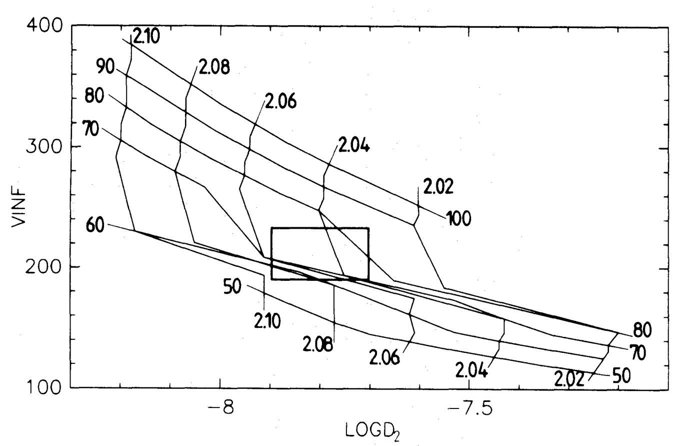

Fig. 8. v_∞ versus $\log D_2$ for a grid of models for P Cygni. $T_{\rm eff}=19\,300$ K and the force multiplier parameters of Table 5 have been adopted. Curves of constant $\log g$ (between 2.02 and 2.10) and $R/R_\odot$ (between 50 and 100) are labelled. The complicated topology of these curves is induced by the transition from domain I to III in Fig. 7. The rectangle indicates the observations of P Cygni

analysis of winds based on radiation driven wind theory does provide accurate information about $\log g$.

The radius uncertainties transform to $\Delta m = ^{+0.27}_{-0.67}$ magnitudes. This is again promising for future work (see next section). The uncertainty in mass, as for ζ Puppis, is of the same order as for conventional photospheric spectroscopy when the distance is known in advance.

We conclude that the method also works for extreme supergiants with very strong winds.

5. Future work

It is evident that accurate observations of mass-loss rate and terminal velocity provide an excellent tool for the determination of stellar masses, radii and distances, if the predictions of the theory of radiation driven winds are correct. As a consequence, two questions are important. How reliable is the theory and how accurately can v_∞, $\log D_2$, $\log D_1$ be determined for objects fainter than those discussed in this paper?

The obvious way to demonstrate the reliability of the theory is the comparison with observations of a large sample of galactic objects with well known distances (from cluster membership) that will have to be studied by the use of quantitative spectroscopy of photospheres and winds (see Kudritzki & Hummer 1986). This work is underway.

An important step will be to investigate whether the predictions of the theory with regard to the metallicity dependence of v_∞ and $\dot{M}$ are correct. The massive hot stars in the Magellanic Clouds are ideal for this purpose (see Kudritzki et al. 1989, 1991a, b; Heap et al. 1991). Therefore, a large spectroscopic project on hot stars in the clouds utilizing ESOs large telescopes and the Hubble Space Telescope has been started. We feel confident that these extensive observational programs combined with theoretical work on the radiation-driven and expanding atmospheres of hot stars will finally lead to a trustworthy theory covering a range of 1.5 dex in metallicity.

With present day telescopes and focal equipment quantitative spectroscopy of massive blue stars in Local Group galaxies beyond the Magellanic Clouds is also possible. Such projects have already been started at our Institute. We again feel confident that using the optimal compromise between spectral resolution and signal-to-noise ratio a good determination of $T_{\rm eff}$, $\log g$, abundances, v_∞ and $\dot{M}$ can be found from the spectra.

Two problems appear to be crucial for the determinations of distances. The uncertainties in mass-loss rate (or $\log D_2$, $\log D_1$) and the so-called crowding-problem of massive hot stars. The adopted uncertainties of ± 0.1 dex for $\log D_1$ and $\log D_2$ are certainly realistic for ζ Puppis and P Cygni. However, will this be achievable for objects where no radio observations are available? In principle, the information contained in wind emission lines in the optical and infrared part of the spectrum such as He II 4686, Hα, He I 10830, He II 10125, should allow $\log D_2$ to be obtained with the same precision as that of radio observations for nearby objects (see Leitherer 1988, 1989). However, the recent work by Drew (1990) and Gabler et al. (1990) has revealed that certain "offsets" to radio mass-loss rates might exist. These offsets could lead to systematic errors for $\log D_2$, if only the information from emission lines were to be used. As a consequence, the investigation of the reliability of $\log D_2$ obtained from these lines and an improvement in the line diagnostics will have high priority.

The crowding-problem describes the fact that most of the known O-stars are found in associations. For a distant galaxy this would mean that the light passing through the entrance aperture of the spectrograph comes from a number of stars rather than one single object. If those objects were all of similar spectral appearance, a large error would be introduced if the spectrophotometric brightness were to be attributed to one single object. The best way out of such a situation would be the use of extremely luminous B-supergiants. Since we can handle their atmospheres and winds, as we have demonstrated for P Cygni, they are very good candidates for the following reason. Such supergiants are rare in normal associations, and thus a contamination with similar spectral types appears to be unlikely. Contamination from O-stars, on the other hand, should be detectable in the spectra, if present. In such a case, one could either try to subtract the contribution of the "O-star background" or concentrate only on those observations where no trace of other spectral types is found. The quantitative spectroscopy of early supergiants for the purpose of distance determinations will, therefore, be of great importance in the future.

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