MASS-LOSS RATES FROM EARLY-TYPE STARS*

Peter S. Conti and Catharine D. Garmany
Joint Institute for Laboratory Astrophysics
University of Colorado and National Bureau of Standards

ABSTRACT

We have derived mass loss rates for a number of unevolved O-type stars and a few WN stars from high dispersion IUE spectra of their P Cygni profiles. When combined with other published mass loss rates, we find that the relationship between log $\dot{m}$ and M_{BOL} is a broad band rather than a linear relation, suggesting that the line radiation driven wind theory may not be sufficient to explain mass loss. The mass loss rates for the WN stars, while more uncertain, confirm that these stars lose mass about 100 times faster than O-stars.

INTRODUCTION

It has been known for many years that early-type stars are losing mass. The first evidence came from rocket UV observations of P Cygni profiles of resonance lines (1), and later determinations of mass loss have come from infrared studies (2), emission lines in the visible (3) and radio observations (4). The observed mass loss has been attributed to UV line radiation pressure (5). In this theory, the mass loss should be proportional to the stellar luminosity, and indeed, observations of O supergiants and Of stars support this. However, our initial IUE observations of five main sequence stars resulted in mass loss rates much lower than the predicted values (6). It is important to find the reason for such a difference, not only for its bearing on theories of mass loss from these stars, but also because stellar evolutionary calculations are affected (7). Our understanding of the atmosphere of early-type stars has been further complicated by the recent Einstein Observatory observations that many of these stars are X-ray sources (8). We have observed an additional 16 main sequence O-stars during the second year of IUE, and have confirmed our earlier finding: at a given luminosity stars are observed to have mass loss rates which differ by a factor of 30.

APPEARANCE OF THE SPECTRA

In the O-type stars, the P Cygni profile of the C IV λ1548 and N V λ1232 resonance doublets are the most consistent indicators of mass loss. Among the earliest spectral types the C IV line is characterized by a sharp blue absorption edge and a terminal velocity greater than 3400 km s^{-1}. At

*This work supported by NASA under grant number NAS5-22833.

later spectral types, the blue edge of the profile becomes less steep and the terminal velocity decreases. However, as illustrated in Figure 1, the degree of line saturation is not related to the bolometric magnitude of the star.

In general, the same description that applies to C IV also applies to the N V line, although blending with Lyman α makes the determination of a terminal velocity uncertain. Both of these lines are fully saturated in the WN stars.

The appearance of the N IV λ1718 line is strongly temperature dependent. In the latest O-type stars it is photospheric, but with increasing effective temperature it develops a blue wing and eventually appears as a P Cygni profile, although the blue edge never reaches the terminal velocity of the strong resonance lines. All of the WN stars show an unsaturated P Cygni profile whose blue edge reaches the same terminal velocity as the other lines.

The Si IV λ1393 resonance doublet is photospheric in all of the main sequence O-stars, but it becomes a saturated P Cygni profile in the O supergiants and late WN7 and WN8 stars. See Figure 2.

MODEL FITTING

We have found mass loss rates for the stars by comparing their P Cygni lines with the model profiles computed by Castor and Lamers (9) and modified by Olson (unpublished) to include nonlocal radiative coupling for doublet profiles. The line profile in an expanding atmosphere is determined by the mass loss rate, the velocity law, the ion abundance, the stellar radius, and atomic parameters. Castor and Lamers have parameterized their models according to the total optical depth and the assumed velocity law, and each observed line profile is then fit by these parameters. The mass loss rate is then derivable from the profile parameters, the terminal velocity, the stellar radius, and the fractional abundance of the absorbing ion. We have used this approach, which is also discussed by Conti and Garmany (6) and applied to a few stars observed during the first year of IUE. One of the most difficult assumptions in this method is the ionization fraction. When two or more nonsaturated P Cygni profiles are seen in the same star, the relative ionization fractions can be computed, and compared with calculated fractions for a given temperature and density, which has been our approach. All of the O-stars are cluster members with well-established bolometric magnitudes. We have adopted Conti's (10) temperature scale in our determination of ionization balance and stellar radii.

RESULTS

We have derived mass loss rates for 16 O-type stars of luminosity class V or III. The rates range from 10^{-6} $M_{\odot}$ yr^{-1} to 2×10^{-9} $M_{\odot}$ yr^{-1}, and the rates are not linearly related to stellar luminosity as predicted by the line radiation driven wind theory. In Figure 3 we show log $\dot{m}$ vs. M_{BOL} for the stars we observed, as well as stars with mass loss rates derived by other methods. For a given M_{BOL}, the rates differ by as much as a factor of 30. The higher rates may be associated with stars which have left the ZAMS but are still burning hydrogen in their core.

We have also calculated mass loss rates for several WN stars, which are shown in Figure 3. The method used was the same as for the O-stars, although the greater uncertainty in the temperatures, ionization fractions, and luminosities make an error estimate difficult. However, we note that our values are similar to those found from observations by Willis (private communication).

These results will be reported elsewhere in more detail.

REFERENCES

1. Morton, D. C.: 1967, Astrophys. J. 150, 535.
2. Barlow, M. J. and Cohen, M.: 1977, Astrophys. J. 213, 737.
3. Conti, P. S. and Frost, S. A.: 1977, Astrophys. J. 212, 728.
4. Abbott, D. C., Bieging, J. H., Churchwell, E. and Cassinelli, J. P.: 1980, Astrophys. J. (in press).
5. Castor, J. I., Abbott, D. C. and Klein, R. K.: 1975, Astrophys. J. 195, 157.
6. Conti, P. S. and Garmany, C. D.: 1980, Astrophys. J. (in press).
7. Chiosi, C., Nasi, E. and Sreenivassan, S. R.: 1978, Astron. Astrophys. 63, 103.
8. Harnden et al.: 1979, Astrophys. J. 234, L51.
9. Castor, J. I. and Lamers, H.J.G.L.M.: 1979, Astrophys. J. Suppl. 39, 481.
10. Conti, P. S.: 1976, Mem. Soc. Roy. Sci. Liege 9, 193.

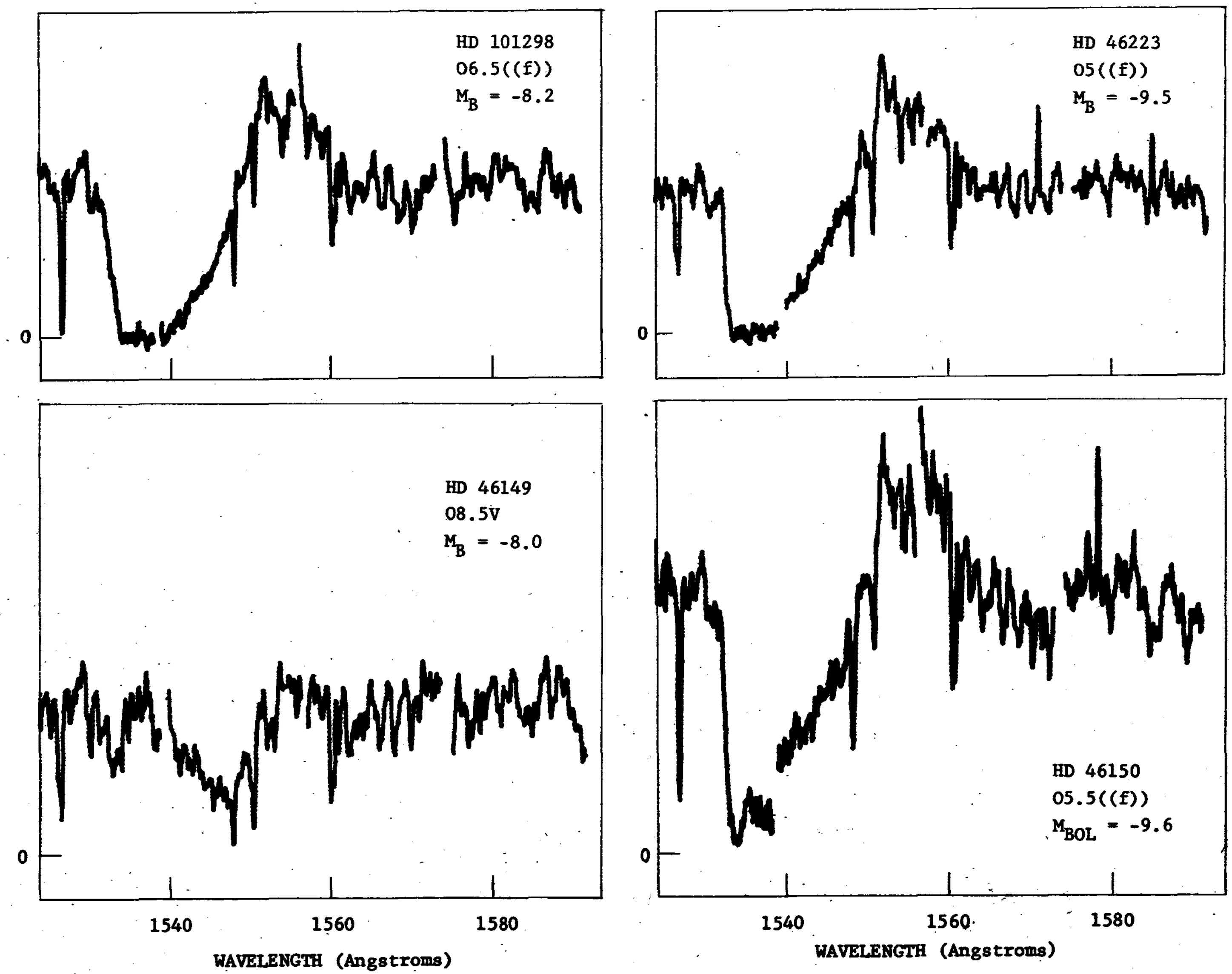

Fig. 1: Line profiles of C IV λ1548,1550 in four O-type stars. IUE observations taken with the SWP camera in October 1979.

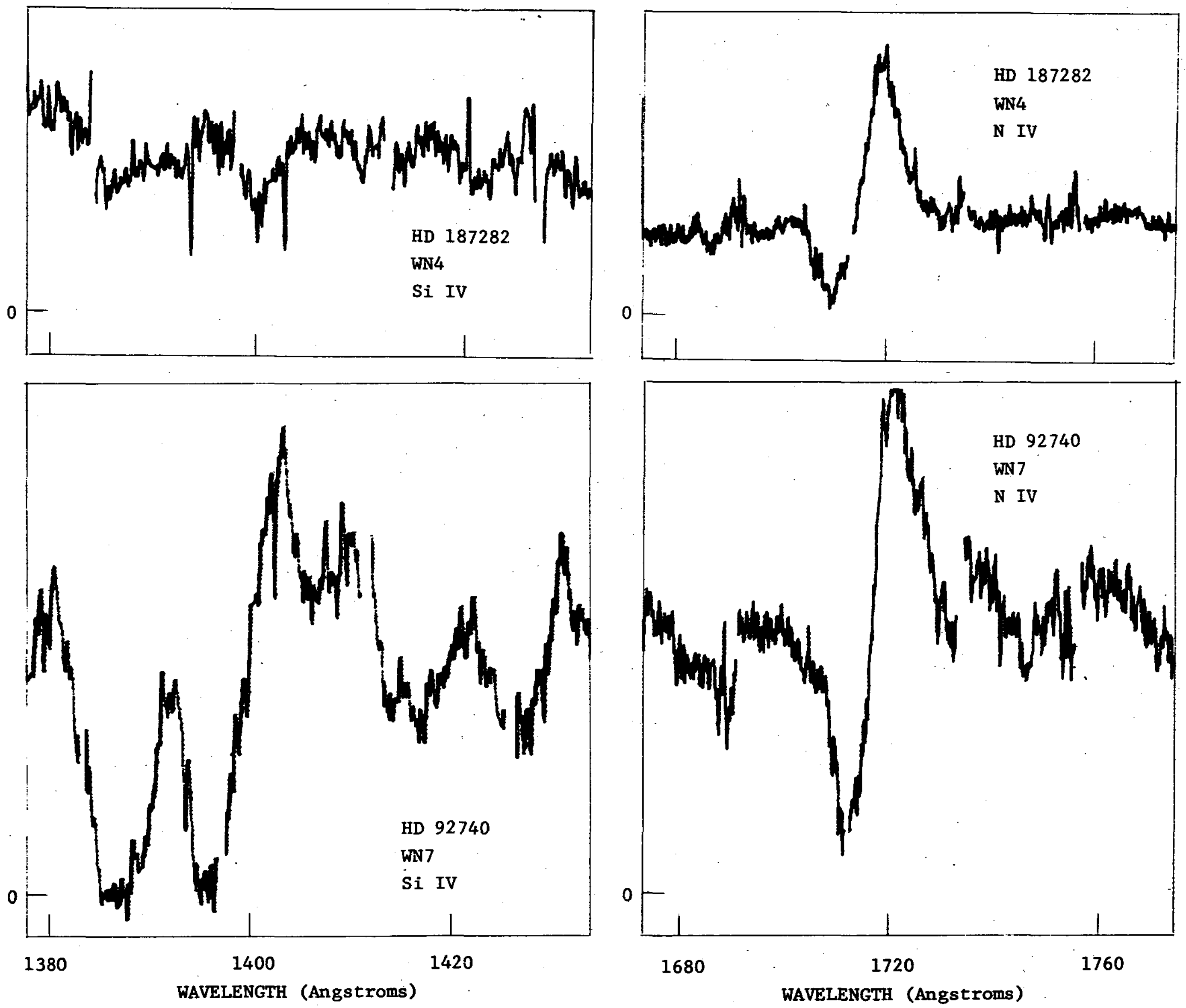

Fig. 2: Line profiles of Si IV λ1393,1402 and N IV λ1718 in a WN4 and WN7 star.

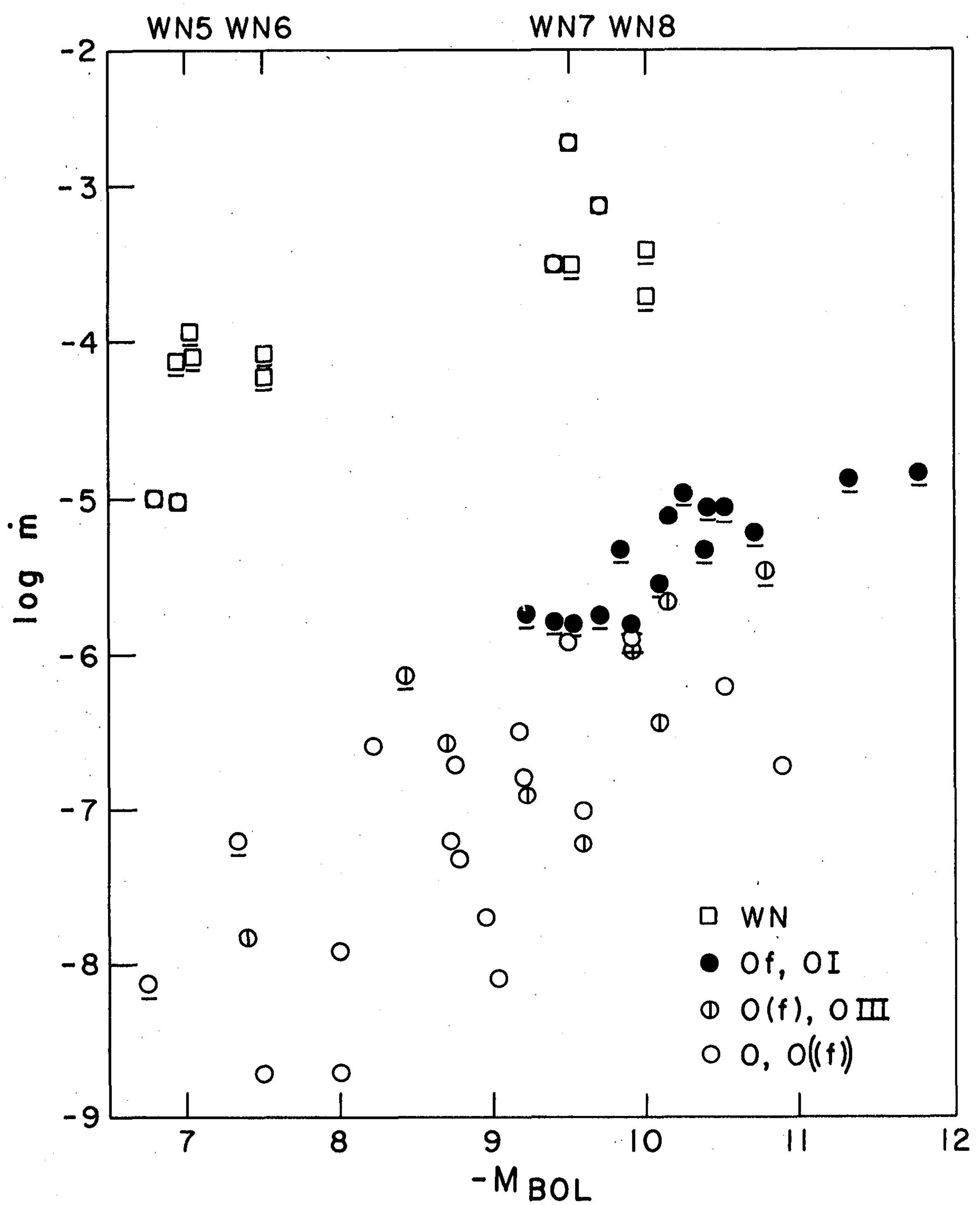

Fig. 3: Mass loss, log ṁ, vs $-M_{BOL}$ for various early-type stars. Rates measured by other methods are underlined, our new determinations are not.