THE MASS LOSS RATE OF γ VELORUM

PETER D. NOERDLINGER
Department of Astrogeophysics, University of Colorado
and High Altitude Observatory of NCAR, Boulder Colorado

1. INTRODUCTION

The CIII λ 1909 absorption feature (deepest at V=-1600 Km s^{-1}) in this star, observed by Burton et al (1975) and Johnson (1978), was predicted by Castor and Nussbaumer (1972). It implies a copious flow of CIII ions, because the oscillator strength is only $f_{ik} = 1.6 \times 10^{-7}$.

The rate of mass loss can be found two ways: (1) there must be enough CIII to produce the absorption, but not so high an n_e as to fill it in or exceed the observed emission wings by collisional excitation. This limits the H/C and He/C ratios, as well as CII and CIV. (2) One uses radio emission (Wright and Barlow 1975; Seaquist 1976; Morton and Wright 1978). The optical method (1) is mildly sensitive to the velocity law and assumed ionization structure. The radio method (2) is sensitive to the assumed mean atomic mass per ion μ, the rms ionic charge Z, and the number of electrons per ion, γ. It proved advisable to construct a large number of computer models combining the two methods. For clarity, I first estimate flow parameters analytically, then give computer results. All methods lead to these conclusions:

The mass loss rate is in the range 1.1-1.4 x 10^{-4} $M_{\odot}$ yr^{-1}. The hydrogen content is very small, and the ratio He/C by mass is < 30, more probably 2-4 (Nugis 1975). The CIII absorption region does *not* surround the O star, but lies within 2-3 stellar radii of the WR star. The O star is therefore deficient in UV near λ1909. I have even examined the data of Ganesh and Bappu (1967) to see if the photospheric He II λ4200 usually attributed to the O star (Conti and Smith 1972) could instead follow the WR star velocity. A statistical test showed, in spite of the great scatter, that the chance is less than 6% that λ4686 and λ4200 are in phase. Thus, the O star is peculiar, rather than actually being a B star, which would be simpler. In Section 2, I clear up some discrepancies on the radio method. Sections 3 and 4 consider CIII absorption and emission, and Section 5 combines methods.

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2. OVERVIEW OF THE RADIO METHOD

Wright and Barlow (1975) showed for a uniform temperature wind, the mass loss rate is (all such rates will be given in solar masses/yr)

$$-\dot{M} = 0.095\ \mu V_t\ S^{3/4}\ D^{3/2}/(Z\gamma^{\frac{1}{2}} g^{\frac{1}{2}} \nu)$$

where V_t is the terminal velocity in Km s^{-1}, S the radio flux in Jy, g the Gaunt factor (=6.9), D the distance in pc (=450), and ν the frequency. Seaquist appears to have taken the mean *ionic* mass μ= 1/2, which does not hold even for hydrogen (μ=1). Using V_t=1000, he got a low $\dot{M}$=-2×10^{-5}. Morton and Wright used the newer V_t=2900, but took μ= 1.3, again low, finding $\dot{M}$= -4×10^{-5}. I find μ in the range 4-9, and within this range the factors Z and γ compensate so as to yield a small range of mass loss rates $\gamma = n_e/n_i$.

3. OPTICAL CONSIDERATIONS: CIII ABSORPTION

Aside from the interesting CIII λ1909 P Cygni feature, this star has a strong CII λ1335 P Cygni profile with a flat top, showing depletion of CII at low velocity. The strong CIV λ1550 P Cygni profile peaks at V=0 and extends over the whole velocity range, which is one reason to think that not much HeII becomes neutral in the wind. The f_{ik} for these lines are so strong that no interesting lower limit is set on their abundances in the flow. He I λ10830 is in strong emission (Barnes et al 1974), but this does not require a predominance of HeI over HeII. The Pβ emission is probably from the O star wind. I shall now show that the CIII absorption ($r_\nu \sim 0.35$) although not washed out by the O star, cannot result from material overlying it. To understand this, consider the CIII number density N_3, the velocity gradient v'= dV/dr, and the optical depth τ where the deepest λ1909 absorption is formed. In cgs units, Castor (1970) showed $\tau=0.0265\lambda f_{ik}N_3/v'$. (More complete dependences on ray angle are included in the computer program). We can estimate N_3/v' as $N_3\Delta r/\Delta V$, with Δr the thickness of the absorption region and ΔV the spread in velocity there. From the spectra, $\Delta V >$ 4×10^{7} cm s^{-1}, so for $\tau>2$ the column density $N_3\Delta r$ must exceed 10^{21} ions cm^{-2}. Then $N_3>10^{21}/\Delta r$. If we take $\Delta r\sim0.1$ r, the outflow of CIII ions is $4\pi r^2 VN_3 > 2\times10^{43}\ r_{12}$ ions s^{-1}, where $r_{12}= r/10^{12}$cm. At the photosphere $r_{12}\sim1$, but in the absorption region it could be 1.5-4.0 (region around WR star only) or $r_{12}>30$ (region surrounding both stars). In the latter case the mass loss rate in CIII would exceed 2×10^{-4}, to which one must add He, CII, and CIV. Besides its implausibility, such a high choice of mass loss would force the radio and CIII emission to exceed observation; thus $r_{12} < 4$ in the CIII absorption region.

4. OPTICAL CONSIDERATIONS: CIII EMISSION

The CIII collisionally excited emission must not fill in the absorption, nor produce emission wings in excess of the observed 7×10^{47}

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photons s^{-1}. By using the excitation rates of Flower and Launay (1973) and some methods from Osterbrock 1970) one can show that in the T and n_e ranges of interest there are about 2-3 x $10^{-9}n_e$ excitations per ion per second. The computer model considers de-excitation and escape probability, with full angle dependence. The conclusion is that, up to a model-dependent uncertainty of a factor 2 or 3, there cannot be more than 3 electrons per CIII ion and still permit the absorption feature; about $5/r_{12}$ electrons per CIII ion are right to produce the emission wings. Thus, r_{12} is again expected to be a small number, say of order 1.5-3.0. Beyond this radius, CIII must recombine to CII , or the temperature T drop below 20,000 K.

5. MASS LOSS. FINAL RESULTS.

A grid of computer models, with velocity law $V=V_t(1-r_{core}r^{-1})^p$, $0.25<p<1.5$ would fit all the radio and optical data only if the O star continuum at 1909 Å was rather less than that of the WR star, and the ratio of He/C by mass was <30. By contrast, if a star with cosmic abundances burned all its H to He, it would have He/C=300. This is forbidden by the data. There would be too many electrons in the CIII absorption region, and in addition, almost all the He would have to become neutral by the time it reached the radio region. It would not do to just reduce the CIII density to compensate the increased He, and so suppress extra radio and CIII emission, because then ther CIII optical depth would be too small to produce the observed absorption. All viable models, with He/C as low as 1 or as high as 30, gave mass loss rates in the range 1.1-1.4 x 10^{-4} solar masses yr^{-1}.

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DISCUSSION FOLLOWING NOERDLINGER

Abbott: What is the velocity of the CIII 1909 absorption fetaure?

Noerdlinger: It runs to about 1800 km s^{-1}

Castor: To reconcile the total mass loss rate with the CIII loss rate and the C/He ratio, you need 100% CIII. Is that a problem? I would expect C to be mostly CIV.

Noerdlinger: I allowed a little in the mass loss rate for CIV, which is seen in the spectrum. There cannot be much present or there will be too many electrons and the CIII 1909 absorption will fill in, also the emission part will become too strong.

Morton: γ Vel has the strongest CII P Cygni resonance line that I have seen in any star. Since single O and hot B stars do not have such CII, it must originate in the WR wind. In any model of this system, it is important to explain the CII feature, particularly the small amount of residual light at the bottom of the CII absorption.

Noerdlinger: I had missed this point, but the CII oscillator strength is so large that CII/CIII can be small and you still get a P Cygni line.

Willis: At what binary phase were your CIII 1909 observations made? The observations of γVel show the strengths and profiles of many lines undergoing strong variations as a function of binary phase. We believe that at some phases absorption of the O-star light in the WC8 stellar wind can take place, and can depress the absorption below the O-star continuum level, even though the O-star is the brighter component.

Noerdlinger: The phases were all near 0.65. At that phase there is no possibility for the WR CIII absorption region to overlie the O-star, or the mass loss rate would come out much too big, and the CIII emission too strong.

Willis: The CII 1335 Å line in γ^2Vel is known to undergo phase dependent variations in its profile, which is believed to be the result of absorption of the O-star in the WC8 wind. We thus think the CII is associated with the WC8 star.

Noerdlinger: This is a valuable observation and I would expect it is quite reasonable; the CII oscillator strength is much bigger.

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