WIND MODELS FOR ζ ORIONIS

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INTRODUCTION

Several models for the winds of O stars have been proposed to explain the unexpected presence of high ionization potential ions such as N^{+4} and O^{+5}. Lamers and Snow (1978) proposed that the winds of stars showing N V and O VI lines have elevated temperatures near $4\pm2 \times 10^5$K while cooler stars with anomalous Si IV lines have $T_e \approx 7\pm3 \times 10^4$K. Alternately, Cassinelli and Olson (1978, CO) and Olson (1978) have explained the presence of these ions by showing that a thin corona at the base of a cool wind ($T_e \lesssim T_{eff}$) can produce these ions by the Auger photoionization process where a single x-ray photon causes the ejection of two electrons. A third possibility is that the winds are at only slightly elevated temperatures (40 000 to 60 000K) and photoionization in an optically thick wind produces the unexpected ions. The problem of determining the local radiation field in such a wind is discussed by Klein and Castor (1978). The purpose of the present analysis is to test the ability of these three wind models to fit the observations of ζ Orionis A O9.7 Ib.

THE OBSERVATIONS AND THEIR ANALYSIS

The ultraviolet resonance lines of ζ Ori have been taken from the *Copernicus* catalog by Snow and Jenkins (1977) and from Snow and Morton (1976). The continuum on both sides of each line was examined to determine the continuum level which was then linearly extrapolated through the line profiles. These normalized profiles were then fitted with theoretical profiles calculated with the Sobolev approximation. The procedure used here for line profile fitting has followed the approach of Olson (1978). The result for each ion with a resonance line is a number that gives the mass loss rate times the relative ionic abundance. Since models will predict the ionic abundances, the mass loss rate of the wind can be determined.

P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 257–260.

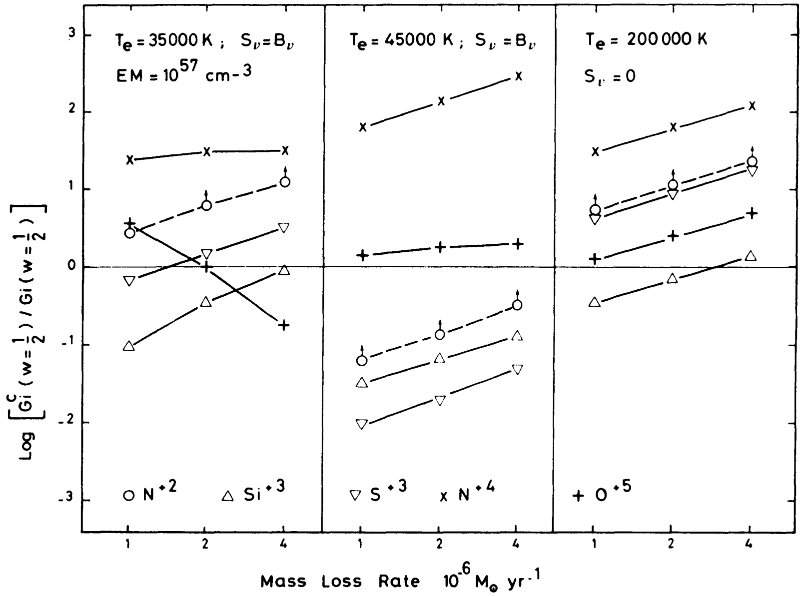

Figure 1. Comparison of computed (G_i^c) to observed (G_i) ionic abundances.

DISCUSSION OF WIND MODELS FOR ζ ORIONIS

Given the temperature and velocity structure of the wind, the ionization balance for the elements of interest can be computed by including the following processes: collisional ionization and photoionization from the ground level, Auger ionization of K-shell electrons, radiative recombination, and dielectronic recombination (see Olson 1978 and CO for details). The radiation contributing to photoionization includes the photosphere, the corona and the local wind radiation at wavelengths where the wind is optically thick. The velocity structure of the wind enters into the calculation primarily through scaling the optical depths. However, since the temperature differences among the three models affect the optical depths much more than the uncertainties in the velocity structure, there will be no discussion of velocity structure effects presented here. The same velocity law will be used for all three models.

A comparison for five ions between observations and theory for the "warm" wind model is shown in the right most panels of Figures 1 and 2 for two gas temperatures. The comparison is made for a range of mass loss rates considered appropriate from Hα analyses. The radiation from the wind has been neglected in the photoionizations because at these elevated temperatures the Non-LTE thermal source function, S_ν, is quite small. Clearly, from these figures the N^{+2} limit (shown as a limit with arrows because the observed N III doublet appears to be photospheric and can only put an upper limit on N^{+2} in the wind) requires a gas tempera-

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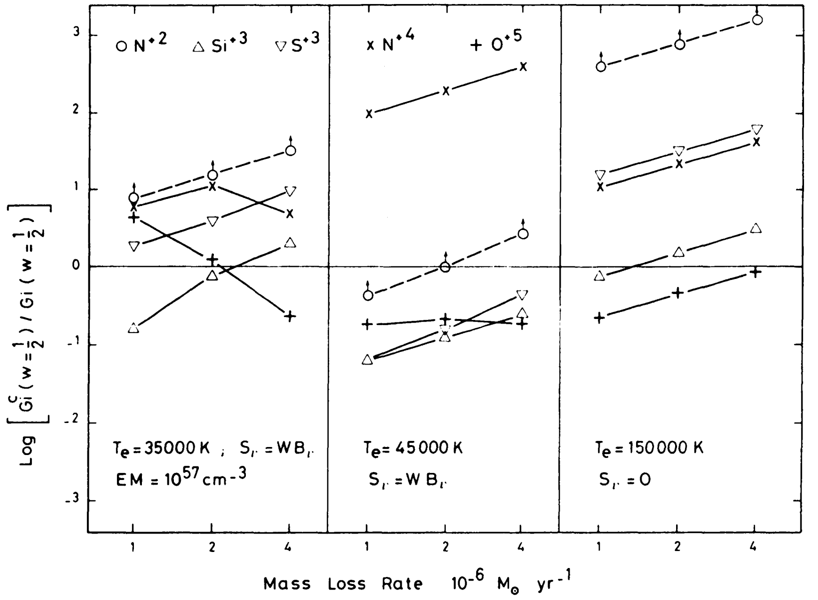

Figure 2. Same as Figure 1.

ture greater than 200 000K. However, at such a temperature this would predict that the N V line should be saturated in the blue shifted absorption, whereas the observed line goes down to only 0.4 of the continuum level. Though Si^{+3} and O^{+5} agree nicely between 150 000K and 200 000K, none of the other ions agree well.

For computing the models with cooler winds, the radiation from the wind has been included in two ways: i) $S_\nu = B_\nu(T_e)$, a blackbody at the wind temperature, ii) $S_\nu = WB_\nu(T_e)$ a blackbody modified by geometrical dilution, W. Case (i) represents a completely optically thick wind and case (ii) a thin wind where the source function is a blackbody modified by the ground level departure coefficient which is inversely proportional to the dilution: $S_\nu = B_\nu/b_1 = WB_\nu$. The true situation is between these two approximations and quite difficult to compute (see Klein and Castor, 1978).

Figure 1 shows that without a corona the wind temperature must be raised to 45 000K to produce the observed abundance of O^{+5}. In this "tepid" wind model N^{+2} is not a problem; however, N^{+4} is overproduced by a factor of 100. Also Si^{+3} and S^{+3} are strongly depleted by this radiation field. Reducing the radiation field by using $S_\nu = WB_\nu$ (Figure 2) lessens this latter problem, but then not enough O^{+5} is produced.

With a coronal model ($T_c = 5 \times 10^6$K) the volume emission measure of the coronal zone, EM $\equiv \int N_e^2\, dV$, is adjusted to provide enough soft x-rays to produce the observed abundance of O^{+5} by Auger photoionization.

For ζ Ori this requires an emission measure near 10^{57} cm^{-3}. Then the wind temperature can be adjusted to minimize the disagreement between the other ions and observations. The results with T_e = 35 000K are shown in the figures. Though the nitrogen ions are still difficult to fit, this model clearly matches the observation better than the other models. Part of this improvement is of course due to the fact that there are two adjustable parameters (T_e, EM) rather than one (T_e).

If nitrogen were underabundant in ζ Ori by a factor of ten, all the models would match the observations much better (especially the corona - cool wind model). However, this is unlikely. The present rough model calculations indicate that the corona-cool wind model fits the observations of ζ Ori better than either the "warm" or "tepid" wind models. However, much more detailed calculations need to be completed before one or more models can be definitely eliminated.

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DISCUSSION FOLLOWING OLSON

Morton: The behaviour of the NIII resonance line in various OB stars is very puzzling. In many cases where the CIII λ977 is present with a velocity displacement, the NIII, which requires higher ionization energy, is an undisplaced photospheric line. ζ Pup is a notable exception with a well developed P Cygni NIII profile.

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