ROCKET OBSERVATIONS OF MASS LOSS FROM HOT STARS*

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Abstract. Rocket observations have shown that the far-ultraviolet resonance lines have P-Cygni profiles in the spectra of many hot stars, including of and Wolf-Rayet stars and OB supergiants. Velocity shifts as high as \(-3000\) km sec\(^{-1}\) have been measured for the short-wavelength edges of some of the lines. Estimates of the rates of mass loss range from \(10^{-8}\) to \(10^{-6}\) M\(_{\odot}\) year\(^{-1}\).

Rocket observations of far-ultraviolet stellar spectra have provided evidence of mass loss from hot supergiants at remarkably high velocities. Absorption lines of the resonance transitions of C\(\text{IV}\), N\(\text{V}\), S\(\text{II}\), and S\(\text{IV}\) have been found with shifts towards shorter wavelengths corresponding to Doppler velocities of \(1000\) to \(2000\) km sec\(^{-1}\) (Morton, 1967; Morton et al., 1968). A tracing of the ultraviolet spectrum of \(\zeta\) Orionis is reproduced in Figure 1 showing the P-Cygni profiles of the C\(\text{IV}\) and S\(\text{IV}\) resonance lines and the displaced absorption lines of C\(\text{III}\), N\(\text{V}\), and S\(\text{III}\). In the expanding shell, where we presume these lines are formed, the dilution of the radiation and the low particle density leave few ions in excited states, so that we expect mainly absorptions from the ground states. Since the higher ion states present in these hot atmospheres all have their resonance lines in the ultraviolet shortward of the atmospheric limit, we can understand why large wavelength shifts have not been seen in ground-based spectra. Nevertheless Wilson (1958) did report evidence of weak, very broad emission lines of He\(\text{II}\), C\(\text{III}\), and N\(\text{III}\) in the visual spectra of some OB supergiants.

More recent rocket observations by several investigators have confirmed and extended the data on the large wavelength shifts of ultraviolet absorption lines. Carruthers (1968) of the U.S. Naval Research Laboratory has photographed spectra of stars from Orion to Vela with a windowless image intensifier; Stecher (1967) of the Goddard Space Flight Center has recorded spectra of several stars.

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Fig. 2. Photograph of the far-ultraviolet spectrum of ζ Puppis from 1100 to 1965 Å obtained by Princeton on November 1, 1967. The labels identify the interstellar HI Ly-α line and the displaced circumstellar features. The tails on the zero-order images resulted from a failure of the fine stabilization 100 sec after the beginning of the exposure.

with a scanning spectrometer; and Morton et al., (1969) of Princeton have reported on the spectra of ζ Puppis and γ² Velorum obtained with an all-reflective objective spectrograph. Figure 2 is a photograph of the Princeton spectrum of ζ Pup showing the shifted circumstellar lines. The HeII, NIV, NV, and CIV features have both emission and absorption components, while the CIII, SiII, and SiIV lines appear only in absorption.

Table I summarizes the data presently published on displaced absorption lines in ultraviolet stellar spectra, with the best estimates of the Doppler velocities of the line centers. Since the Princeton spectra have the highest resolution, their velocities are quoted in most cases when available; otherwise Carruthers' results are listed. An 'e' indicates an emission line also is present at approximately its laboratory wavelength. The surface escape velocity is on the order of 600 km sec⁻¹ for the supergiants and perhaps twice this for γ² Vel and ζ Pup. Since all the stars have some lines shifted in excess of the escape velocity, mass loss must be occurring.

We see that in some of the stars the shifts also have been detected in absorption lines of HeII, CIII, and NIV from excited levels. Except for the CIII line in the two hottest stars γ² Vel and ζ Pup, the excited lines tend to have smaller outward velocities than the resonance lines. The excited lines must be formed lower in the atmosphere, in the acceleration zone, where the density is higher. The velocities are more negative with decreasing excitation potential similar to the correlation found for the much smaller shifts in the visual spectra of P Cyg and some OB supergiants.

There now is evidence of high-velocity mass loss in enough OB stars for us to conclude that the phenomenon probably occurs in all hot supergiants and in at least some bright giants and giants B0.5 and earlier. However, the evidence for the shifted