SPECTRAL VARIATIONS OF THETA MUSCAE (WC 6 + O 9.5 I) IN THE ULTRAVIOLET

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ABSTRACT - High and low resolution spectra of the spectroscopic triple star θ Muscae were studied for time-variability. Within 7 min no variations were found in the low resolution data. On a time scale of 8 days and longer, variations in the P Cygni profiles of the resonance lines occur. These may be explained as variable mass loss from the system, or as aspect effects in an asymmetric wind flow.

INTRODUCTION

θ Muscae is the second brightest WR star in apparent magnitude, but still not very well understood. It is a visual double star with a B3 II companion, separated by 5".3 (Smith, 1955). Suspected as a spectroscopic binary since 1916 (Cannon), it took till 1977 before a radial velocity study was published (Moffat and Seggewiss). They found that this object is probably a triple system: O + WR + compact companion, in which the latter two revolve around each other with a tentative period of $P = 18^{d}.341$, and together around the O star with a period of the order of 5 years.

Variations in the UV with periodicities of 100 - 200 sec and $1^{d}.5$ have been reported by Burton *et al.* (1978).

The presence of the compact companion may be related to the presence of the ring nebula around the system, which has recently been reported (Chu, 1981; Heckathorn *et al.*, 1981).

The mass loss rate of the system has been determined from IR excess measurements to be $\dot{M} = 3.5 \times 10^{-5}\ M_{\odot}$ / yr (Barlow *et al.*, (1981).

A complete bibliography of θ Mus is given by van der Hucht *et al.*, (1981).

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 311–315.

OBSERVATIONS AND ANALYSIS

We observed θ Mus with the *IUE* low and high resolution camera's in order to study spectral variations between different orbital phases. The low resolution camera was used to obtain trailed spectra: by letting the star image trail over the length of the entrance slit of the spectrograph in 7 min, we obtained a spectrum per image line. At this time scale we found no spectral variations in these data.

In the high resolution spectra of θ Mus the P Cygni profiles of resonance lines are remarkably similar to those of O stars, in the sense that e.g. for a C IV resonance doublet the emission and absorption have almost equal equivalent width, while for single WC 6 stars the emission component is much stronger. This is not surprising, since the O star is 2.5 mag brighter than the WR star (Willis and Wilson, 1978), thus drowning the WR spectrum. For the present paper we studied the C IV resonance doublet only. This is presented in the Figure at five different phases, chronologically arranged. It is immediately obvious that we see no eclipse effects as in the case of γ^2 Velorum (Willis *et al.*, 1979), causing the emission component to disappear at certain phases. This strengthens the conclusion of Moffat and Seggewiss (1977), that we do not see the O star and the WR star orbiting around each other.

The P Cygni profiles were compared with the theoretical profiles for doublet resonance lines as calculated by Olson (1981), in order to determine the mass loss rates corresponding to the individual observations. Allowance was made for the fact that the shortward edge of the C IV profile blends with a photospheric line at 1533 Å, tentatively identified as Si IV (Garmany *et al.*, 1981). We determined a terminal wind velocity $v_\infty = 2540$ km/s. The same velocity was found for C III λ2296. In Olson's formalism the terminal velocity and the doublet separation are related to each other by $\delta = 0.2$. The mass loss rate at each phase can be determined from (Olson, 1981)

$$\dot{M} = \frac{1.18 \times 10^{-18}\ T\ v_\infty^2\ R}{f\ \lambda\ A\ g} \quad (M_\odot\ /\ \mathrm{yr}).$$

For the radius R we adopted $20\ R_\odot$ (Allen, 1973), for the abundance A the solar value, and for the ionisation fraction $g = 0.0025$ (Llorente de Andrés *et al.*, 1981). The optical depth parameter T was found from profile fitting with Olson's theoretical profiles.

We found that T varies from T = 20 ($\phi = 0.11$), via T = 15 ($\phi = 0.02$ and 0.38), to T = 10 ($\phi = 0.88$). Consequently, the mass loss rate of θ Mus seems to vary from respectively 1.1×10^{-5} via 8.2×10^{-6} to $5.5 \times 10^{-6}\ M_\odot$ / yr.

It seems that the smallest mass loss rate is observed when the WR star is almost "in front" of the compact companion. Alternatively this may be interpreted as that the wind is not spherically symmetric around the system, but that aspect effects in the asymmetric flow cause the observed profile variations. More observations are needed in order to confirm the period and to establish the exact nature of the variations.

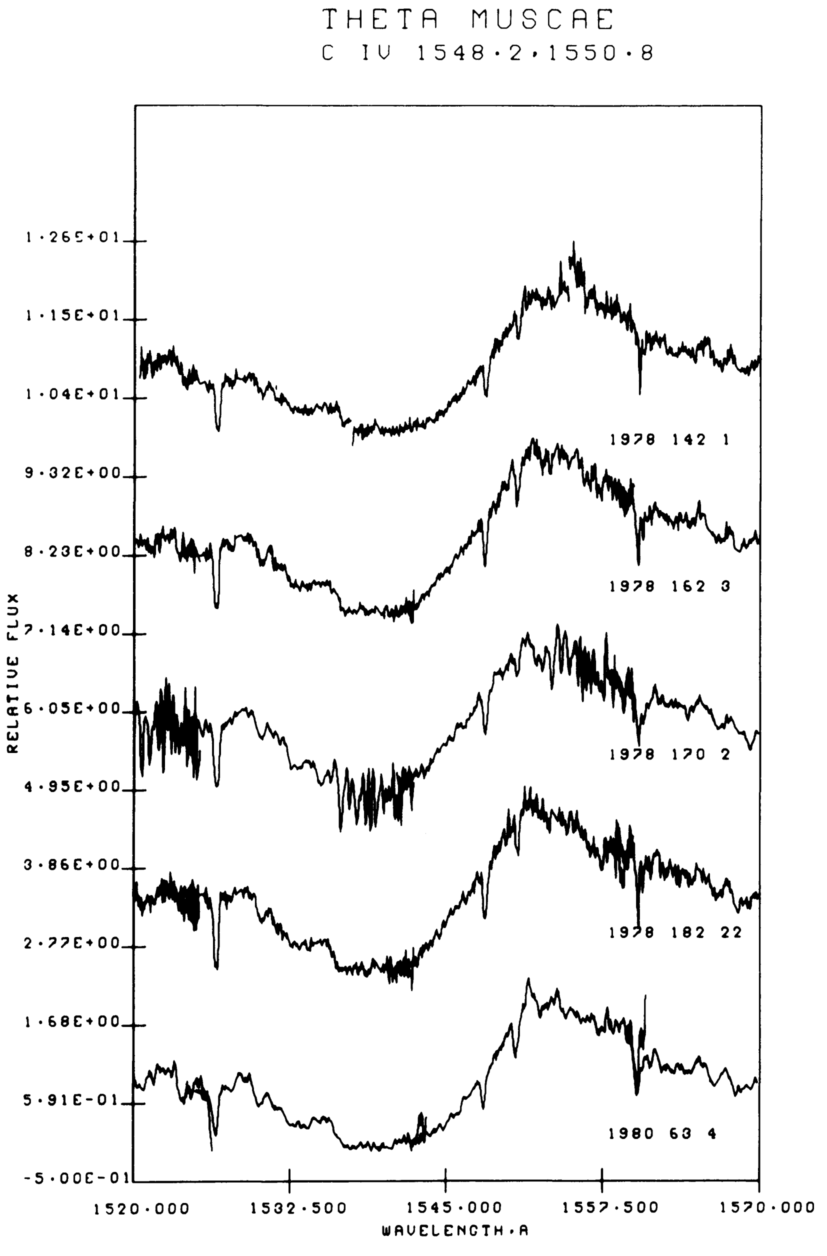

Figure. The C IV resonance doublet of θ Muscae, at respectively the orbital phases φ = 0.88, 0.02, 0.46, 0.11 and 0.38. For each observation the zero flux level is reached by the absorption component of the P Cygni profile.

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DISCUSSION

Moffat: Seggewiss and I already noted that the flat-topped profile of C III 5696 is strongly variable, probably due to strong streaming effects between the WC6 component and its unseen O(?) companion. Since this low-ionization line is probably formed in the outer part of the WR wind, perhaps the UV profile variations you are observing (also in the outer wind) are related to the CIII 5696 variations and thus refer to the WC component.

van der Hucht: That may be. It is very difficult to see from the present data (only five phases) which component is responsible for the observed variations, since the period is not certain.

Garmany: In our study of mass loss from O-stars (Garmany, Olsen, Conti and Vansteenberg, 1981, Ap.J., Nov. 15th) there are a number of main sequence stars with emission in CIV. This extends to as late as O6.5V or O7V.

van der Hucht: In θ Muscae we deal, according to present knowledge with an O9.7Iab component.

Underhill: I should like to caution you about estimating v_∞ from the shortward edge of the absorption trough due to CIV. There are several strong FeIV lines near 1532Å and they blend with CIV in late O supergiants. Your values for v_∞ are nearly a factor of 2 larger that what is normal for O9/BO supergiants.

van der Hucht: The profiles are fairly smooth. A FeIV line strength calculation should be performed to prove your point.

Henize: I agree that the UV SiIV and CIV lines in θ Muscae appear to be due to the O supergiant companion. However, I am puzzled since this contradicts my data in the LMC in which those WC stars identified as binaries show, in most cases, significantly weaker CIV emission than the so-called single WR stars. Why are the O companions and their expected CIV emission not showing up more prominently in the binary stars? Broad-bsed low-dispersion statistics (Henize, Wray and Parsons, 1981, A.J., 86, 1658) show that OV stars hotter than O7.5, OIII stars hotter than O9 and OB supergiants hotter than B1, with very few exceptions, all show strong CIV emission.

van der Hucht: In high resolution and low resolution IUE spectra of galactic WC stars, the appearance of the CIV resonance lines is quite normal.

Massey: I have one comment and a question. The comment is that θ Mus has the largest mass function of any SB1 WR system; the companion could easily be a main sequence O-star (rather than a compact companion) whose lines are hidden by a third body, i.e. the bright O7 supergiant, as discussed by Moffat and Seggewiss (1977, A&A, 54, 607). The question is, how does the UV variability of θ Mus compare to that of γ Vel ?

van der Hucht: Eclipse effects, as found in the UV for γ^2 Vel, are absent in our θ Musccae spectra.

Carrasco: The edge and profile changes you observe are very similar to the ones observed by us last year in single O-type giant stars such as HD 175754, and are indicative of changes in the ionization structure of the winds and probably are showing also changes in the velocity law.

van der Hucht: This is good to know.