MASS FLOW IN THE INTERACTING BINARY TX URSAE MAJORIS

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ABSTRACT

Twenty-two far-ultraviolet and twenty-three near-ultraviolet high resolution International Ultraviolet Explorer (IUE) spectra of the interactive Algol-type binary TX Ursae Majoris (B8 V + F-K III-IV) have been analyzed in order to determine the nature of the mass flow occurring in this system. Absorption features due to high-temperature ions of Si IV, C IV and N V are always present. The resonance lines of Al III, Fe II, Mg II and Si IV show strong phase and secular variations indicative of both gas streaming and circumstellar/circumbinary material. Radial velocities as high as ±500 to 600 kms^{-1} are present. The gas flow was particularly prominent in 1985 between phases 0.7 and 0.0. The system is more active than U Sagittae and about as active as U Cephei.

Keywords: Interacting Binaries; Mass Flow; Ultraviolet Spectra

1. INTRODUCTION

The eclipsing binary TX UMa = HD 93033 is a typical Algol-type binary with a period of 3.06 days. Swensen and McNamara (Ref. 1) noted the presence of variable absorption cores in the Balmer series and attributed this to the presence of gas streams. Numerous photometric studies have been published (e.g., Refs. 2-4). Koch (Ref. 2) found that an extended atmospheric structure was present around one of the components. The photometric solutions are in reasonable agreement indicating that the cooler star is at its critical Roche lobe and is 1.6 to 1.8 times larger than the detached B8 V primary. The spectral type of the secondary component is uncertain with estimates varying from F2 to K5. The value of K_2, the velocity semi-amplitude of the cool component, is not known and the masses are consequently subject to considerable uncertainty. Kreimer and Tremko (Ref. 5) give ranges of 2.8 - 6.1 and 0.8 to 1.8 solar masses for the hotter and cooler components, respectively. They note variations in the depth of primary eclipse as large as $0^m.11$; changes which are not symmetric with respect to phase zero. Oh and Chen (Ref. 6) concluded that a discrete period change of -6 to -7 seconds occurred in 1965 with the period essentially constant before and after that change. Such a period change could be accounted for by a mass transfer of 1.1×10^{-5} solar masses. Mallama (Ref. 7) and Giuricin et al. (Ref. 8) find that the primary star is rotating about three times faster than synchronous rotation would require. It is clear that TX UMa is experiencing mass flow with secular variations.

2. OBSERVATIONS

With the launch of the IUE satellite, it became possible to study mass flow in the ultraviolet spectral region where it has signatures far more observable than in the optical spectrum. In 1980 and 1981, nine high resolution IUE spectra of TX UMa were obtained. Polidan and Peters (Ref. 9) and Peters and Polidan (Ref. 10) have discussed some of these spectra as well as those of a number of other Algol-type binaries. They did not detect C IV or N V in TX UMa but noted the presence and phase dependence of the Si IV resonance doublet stating that it is absent at phase 0.60 in mid-1980 but that it is prominent at phases 0.07, 0.40 and 0.92 later in 1980 and very early in 1981. A gas stream is present at phase 0.92. They found Al III to show similar effects. It is concluded (Ref. 10) that a high temperature accretion region of variable strength and distribution is present in many Algol-systems. The presence of resonance lines of N V, C IV and Si IV in many of these indicates an electron temperature of 10^5K, and an electron number density of $10^9 cm^{-3}$ with a concentration near the following hemisphere of the primary star.

Since TX UMa was obviously undergoing mass flow, McCluskey and Kondo (Program IBHGM) obtained twenty-nine high resolution IUE spectra of TX UMa over one orbital period in June 1985 in order to study phase and secular variations of the mass flow in TX UMa. In addition, nine high resolution spectra were obtained by another program earlier in 1985. The total of forty-five high resolution spectra of TX UMa provided an excellent data set to examine the mass flow in this system. All phases were calculated using the light elements of OH and Chen (Ref. 6).

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3. DISCUSSION

Careful analysis of the data reveals that weak absorption features due to the C IV and N V absorption lines are present at all phases. Phase variations are minimal as are secular variations. The average equivalent widths are 0.39 ± 0.17 Å and 0.42 ± 0.17 Å for λ 1238 and λ 1242 of N V, respectively and 0.38 ± 0.12 Å and 0.37 ± 0.11 Å for λ 1548 and λ 1550 of C IV, respectively. The velocities are subject to considerable uncertainty but for both C IV and N V, while showing variations in the sense of the orbital motion of the primary star, they show a bias of -50 to -150 kms^{-1}.

The Si IV resonance doublet is always present in absorption but shows considerable phase variation. These lines were somewhat weaker at corresponding phases in 1980-81 than in 1985. The equivalent widths of both components of the doublet are 50-100% stronger at phases from 0.78 to 0.97, with the exception of phases 0.83 and 0.93 which were obtained in 1980 and which are among the smallest values measured. There is also a slight (~30%) increase in equivalent width between phases 0.41 and 0.51, as well as at phase 0.077 which was obtained in early 1981. The radial velocities vary roughly with the orbital velocity of the B8 V star but show considerable scatter with a bias of -50 to -100 kms^{-1} between phases 0.0 and 0.6 and +50 to +100 kms^{-1} between phases 0.6 and 1.0. Significant longward absorption equivalent to as much as +540 kms^{-1} is present between phases 0.78 and 0.97. Shortward absorption as high as -500 kms^{-1} is present at phases 0.08 to 0.41. The longward absorption develops somewhere between phases 0.61 and 0.78 where no observations are available.

The Al III resonance doublet behaves very similarly to the Si IV doublet and it is very likely that they arise in close proximity. In the far-ultraviolet spectrum, the absorption lines of C II, Si II, and Si III, appear to be mainly photospheric showing little or no phase variation and yielding radial velocities consistent with the B-type primary star. The Fe III lines at λλ 1895, 1914, 1926 show a modest increase in strength after phase 0.6 with little velocity bias.

The most prominent lines in the mid-ultraviolet spectrum are the resonance line of Fe II at λ 2599 and the Mg II resonance doublet at λλ 2795, 2802. These are all effected by mass flow.

The Fe II resonance line shows increased strength at phases 0.86 - 0.97 with the exception of phase 0.94 observed in 1980 when it was similar in strength to its value before secondary minimum. There is longward absorption of +300 to +400 kms^{-1} at phases later than 0.8. The radial velocities indicate a negative bias of -10 to -60 kms^{-1} at all phases.

The Mg II resonance lines are strongly effected by mass flow, once again particularly after phase 0.77. Longward absorption increases dramatically between phases 0.53 and 0.77. Longward absorption extends from +450 to +550 kms^{-1} after secondary minimum. Weaker shortward absorption to -300 kms^{-1} is present from phase 0.07 to 0.44. Once again the radial velocity varies in the same sense as the primary star and in this case shows no systematic bias toward positive or negative velocities. No emission is detectable in any of the spectra and no strong narrow absorption components appear although weak components may be present in Si IV, Fe II and Mg II in the 0.7 - 1.0 phase range. Continuum intensity measurements were made at numerous wavelengths at all phases. Except for the expected decrease in intensity in primary eclipse no significant ($\gtrsim$5-10%) variations were noted.

It is clear that extensive mass flow is occuring in TX UMa. It is relatively widespread with a concentration of material visible between phases 0.7 and 0.1. The relatively unchanging strength of the C IV and N V lines together with a systematic velocity of -50 to -150 kms^{-1} would seem to imply that these lines are formed at a greater distance from the B-star than are the Al III, Fe II, Fe III, Mg II and Si IV lines. They are probably formed in an expanding volume of gas with some degree of spherical symmetry. Whether this material is circumstellar about the B-star or circumbinary is not clear but line widths indicate some turbulent broadening which might be more readily explained by the circumstellar case.

The behavior of the Al III and Si IV resonance lines is so similar that they must form in the same region. Extreme radial velocities of -500 kms^{-1} and +500 kms^{-1} are present at phases 0.1 - 0.4 and 0.7 - 0.9, respectively. Both ions show a systematic velocity of -50 to -100 kms^{-1} in the 0.0 - 0.6 phase range and +50 to +100 kms^{-1} in the -0.6 - 1.0 phase range. The broad nature of the excess absorption shows that narrow gas streams are not responsible but that a more diffuse flow is present. At phases 0.0 - 0.6 we detect gas which has circled around the B-star and is approaching the observer, while at phases 0.6 - 1.0 gas falling onto the B-star is detected. This also accounts for the great strength of the lines after secondary eclipse since only part of the gas will succeed in circling the B-star and causing the absorption after primary eclipse. The extreme velocities strongly imply that some material is escaping from the system. The Fe II and Mg II resonance lines are more difficult to interpret since significant interstellar and photospheric absorption is superimposed on the overall lines. The Fe II line shows extreme velocities of -300 to +400 kms^{-1} in the same phase relationship as that for Si IV and Al III. Similarly, the Mg II doublet shows a range of -300 to +550 kms^{-1}. No consistent velocity bias greater than 20 kms^{-1} is detectable. The Fe II λ 2599 line shows a small bias of -10 to -60 kms^{-1} at all phases. The Fe III lines show no bias in velocity but are clearly stronger after secondary eclipse.

The Al III, Fe II, Fe III, Mg II and Si IV lines, minus any photospheric contribution, are formed relatively close to the B-star and are part of the diffuse flow surrounding the B-star but concentrated on its following hemisphere. The picture of mass flow in this system is remarkably similar to that found in U Cephei by Kondo et al. (Ref. 11). As noted by McCluskey and Kondo (Ref. 12) for U Sagittae, it appears that a "pseudophotospheric" region surrounds the B-star with a concentration on the following hemisphere. This region is created and energized the the interaction of gas from the cool companion falling onto the B-star. The "pseudophotospheric" lines of Fe II, Mg II and Al III are relatively broad compared with photospheric lines of Si II and Si III but have larger residual intensities. Since the continuum of TX UMa is unaffected by the "pseudo-photospheric" gas, a covering factor phenomenon such as observed for U Cep in outburst (Ref. 13) is unlikely. As suggested by Peters and Polidan (Ref. 10) turbulence is a likely factor in broadening these lines. The accretion of gas from the cool star by the B-star also accounts for the considerably faster than synchronous rotation of the latter.

4. CONCLUSIONS

The interacting binary TX UMa is in a state of active mass flow. In fact it is at least as active as U Cep when U Cep is in its "normal" state. The nature of the flow is quite similar to that of U Cep and, although stronger, to that of U Sge.

It is strongly desirable to obtain more accurate information concerning the secondary component, particularly its velocity semi-amplitude and spectral type. Infra-red measurements during the deepest part of the partial primary eclipse should help to resolve this problem. Since TX UMa mimics U Cep in many ways, it should be regularly monitored for outbursts similar to those of U Cep. In order to better understand the nature of the mass flow and evolution of the Algol-type systems, it is important to find systems undergoing active stages of mass flow. TX UMa is such a system.

One of the authors (G.E. McCluskey, Jr.) was partially supported by NASA Grant 5386 while another (C.P.S. McCluskey) was partially supported by a NASA-ASEE Summer Faculty Fellowship Program. We thank the US IUE project team for their competent assistance in obtaining the data and the Goddard Regional Data Analysis facility staff for their excellent support in the analysis of the data.

5. REFERENCES

1. Swensen, P.R. and McNamara, D.H. 1968, *Publ. Astron. Soc. Pacific*, 80, 192.

2. Koch, R.H. 1961, *A.J.*, 66, 230.

3. Hall, D.S. and Neff, S.G. 1979, *Acta Astron.*, 29, 641.

4. Cester, B., Feder, B., Giuricin, G., Mardirossian, F., and Pucillo, M. 1977, *Astr. Ap.*, 61, 469.

5. Kreiner, J.M. and Tremko, J. 1980, *Bull. Astron. Soc. Czech.*, 31, 343.

6. Oh, K-.D. and Chen, K.-Y. 1984, *A.J.*, 89, 126.

7. Mallama, A.D. 1980, *Ap. J. Suppl.*, 44, 241.

8. Giuricin, G., Mardirossian, F., and Mezzetti, M. 1984, *Astro. Ap.*, 131, 152.

9. Polidan, R.S. and Peters, G.J. 1982, in *Advances in Ultraviolet Astronomy: Four Years of IUE Research*, ed. Y. Kondo, J.M. Mead, and R.D. Chapman, P. 534.

10. Peters, G.J. and Polidan, R.S. 1984, *Ap. J.*, 283, 745.

11. Kondo, Y., McCluskey, G.E., Jr., and Harvel, C.A. 1981, *Ap. J.*, 247, 202.

12. McCluskey, G.E., Jr. and Kondo, Y. 1984, in *Future of Ultraviolet Astronomy Based on Six Years of IUE Research*, ed. J.M. Mead, R.D. Chapman, and Y. Kondo, p. 382.

13. McCluskey, G.E., Jr., Kondo, Y., and Olson, E.C. 1988, *Ap. J.*, in press.