MASS FLOW AND EVOLUTION OF UW CANIS MAJORIS

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ABSTRACT

The far-UV spectrum of the eclipsing binary UW CMa (O7f + O-B) had earlier been utilized to derive a mass-loss rate of about 10^{-6} to 10^{-5} solar mass per year. The mass flow seems to be basically in the form of a stellar wind emanating from the O7f primary component, with radiation pressure as the controlling factor. The main characteristics that make UW CMa a possible progenitor of a Wolf-Rayet system are discussed.

1. INTRODUCTION

The close eclipsing binary UW CMa consists of an O7f star and a late O or possibly B component. It has repeatedly been studied by a number of workers, the latest very detailed investigations are the photometric study by Leung and Schneider (1978), using the Wilson and Devinney (1971) approach, and the spectroscopic analysis by Hutchings (1977). But there are still many unresolved problems associated with this system.

The far-ultraviolet spectrum of the O7f star was first observed in 1973 by McCluskey et al. (1975) near phase 0.75, and then again in 1975 by McCluskey and Kondo (1976) around phase 0.25. Both times the U2 spectrometer of the Copernicus satellite, in the wavelength region from about 950 to 1560 Å at a resolution corresponding to 0.2 Å was used. Recently,

P. S. Conti and C. W. H. de Loore (eds.), Mass Loss and Evolution of O-Type Stars, 281–286.

new IUE observations were made by Kondo and McCluskey in the longer wavelength region between 1200 and 3000 Å. They complement the far-UV Copernicus and the optical observations and thus may help clarify some of the still unresolved problems connected with this system.

2. MASS FLOW

The dominant features in the far-UV region are P Cygni lines of SIV, PV, FeIII, CIII, CIV, NV, and SiIV. When comparing the measurements obtained about phase 0.75 with those obtained at phase 0.25, it appears that the absorption line velocities do not change; they yield radial velocities of about - 500 km/sec. The peaks of the emission components, on the other hand, are shifted by several hundred Km/sec and thus significantly larger than the projected orbital velocity of about 200 km/sec. The radial velocities of the UV absorption lines are stationary and not phase-related; they probably originate in a gas cloud surrounding the entire binary system. Ground-based data obtained and analyzed by Hutchings (1977), on the other hand are related to the orbital phase and show a variable flow from the primary in a non-circular orbit.

From the strength of the absorption component of these lines, a mass loss rate of about 3×10^{-6} M_{O} per year was deduced (McCluskey et al., 1975). This result is in good agreement with the value found by Hutchings (1976) in a ground-based mass-loss survey of hot supergiants.

The effects of radiation pressure on the Roche equipotential surfaces in UW CMa have been discussed by McCluskey and Kondo (1976). It is emphasized that radiation pressure is the controlling factor, not the Roche lobe around the primary. Vanbeveren (1977) has pointed out that the opening of the Roche lobe behind the secondary star (the star with no radiation pressure) could be fallacious as the model neglects the shadowing effect of the secondary star. However, the effect of radiation pressure on the critical lobe surrounding the primary star is probably not far from the original predictions, in which the critical surface, the characteristic figure eight, is not present when the radiation pressure force is nonzero. Castor, Abbott, and Klein (1975) have shown that radiation pressure in the spectral lines of abundant elements can easily give a value of the ratio of the radiation pressure force to the gravitational force for the O7f star, that is equal to or greater than unity, indicating that the mass flow is determined by the nature of the stellar wind emanating from the O7f primary star. The mass does not necessarily flow from component one to component two through the inner Lagrangian point, L_1, to form a gaseous ring surrounding the secondary, but has access to a much larger volume than it has in the case of negligible radiation pressure. The forces giving rise to the stellar wind are apparently at least as important as gravitational, Coriolis or Centrifugal forces, and a well defined model must take these forces and their interactions into account. The use of conventional Roche lobe theory to derive orbital parameters for systems, in which a stellar wind is present, may lead to serious errors.

Applying accretion theory to UW CMa, one finds that the secondary component may accrete from 0.25 to 1% of the mass lost by the primary in its wind. This means that during the stellar wind phase, essentially all of the mass lost by the primary, leaves the system.

3. EVOLUTION

It is well known that most Wolf-Rayet stars appear to be in binary systems, and it has been argued that actually all these stars are binaries.

According to Kuhi (1973) and Bohannan and Conti (1976), a typical Wolf-Rayet system shows redshifted emission lines of +90 to +190 km/sec, a W-R star with an average mass of about 10 $M_\odot$, which is overluminous for its mass, and a companion with a spectral type O5 to B0; the mass ratio, M_{WR}/M_{OB} tends to be between 0.2 and 0.4.

If most - or perhaps even all - W-R stars are in binaries, then there must also be immediate progenitors to that state. In fact, a few close binary systems have already been suggested as being in the process of evolving into Wolf-Rayet binaries.

Massey and Conti (1977) have suggested that the O-type binary HDE 228766 is becoming a Wolf-Rayet binary. Bohannan and Conti (1976) made a similar suggestion concerning BD + 40° 4220.

HDE 228766 consists of an O5.5f and an O7.5 I star, each star having about 16 solar masses. The Of star is losing mass at a rate of about 10^{-5} solar mass per year. As the hydrogen envelope is lost from the Of star, the mass ratio will decrease and eventually this star will become a Wolf-Rayet star with a more massive O-type companion.

Bohannan and Conti (1976) note that in the system BD + 40° 4220, which consists of two Of supergiants with minimum masses of 47 solar masses for the primary and 16 for the secondary, the secondary is overluminous for its mass and has all of the characteristics of a Wolf-Rayet star except for the spectrum. The emission lines are redshifted by about +200 km/sec, and the mass loss is estimated to be about 10^{-5} $M_{\odot}$/yr. The mass ratio of 0.2 is presently the same as that of typical Wolf-Rayet binaries. The authors conclude that BD + 40° 4220 is an immediate progenitor of a Wolf-Rayet binary system.

The characteristics of UW CMa match those of HDE 228766 to some extent. Mass is being lost by the Of star at a rate of 10^{-6} to 10^{-5} $M_{\odot}$/year. The initial mass of the Of star was probably at least 30 solar masses and may have been significantly more. The mass ratio is not certain due to the difficulty of detecting the spectrum of the secondary component but is probably close to unity. The Of star is overluminous for its present mass and also in this respect similar to the Wolf-Rayet star in a Wolf-Rayet binary system. The spectral type of the secondary is late O-type or possibly BO. The emission lines are redshifted by several hundred km/sec.

These characteristics make UW CMa a possible progenitor of a Wolf-Rayet system. As suggested by several investigators, the Wolf-Rayet star may then become a supernova leaving a neutron star or black hole. The companion O-star will then evolve and an X-ray binary might develop.

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DISCUSSION FOLLOWING KONDO, McCLUSKEY and RAHE

Hutchings: It is important to be clear that your non phase-related UV data refer to a circumstellar wind from the system. The ground based data I showed are phase related and show that there is a variable flow from the primary in a non-circular orbit.

Rahe: We hope that the new IUE data obtained at the wavelength region of 1200 to 3000 Å will complement the far-UV Copernicus (950 to 1560 Å) and the optical measurements, and help to clarify this problem.

Wilson: It is important to distinguish between the role of radiation pressure in establishing the figures of binary components and its role in circumstellar gas flows. The important characteristics of the interesting surfaces are quite different for these two problems. For example, the analog of the inner Lagrangian point will be shifted due to radiation pressure at the "L1-point". However, since the von Zeipel law predicts that the radiation flux drops to zero at the L1-point, there will be no radiation pressure to include in considering the maximum size a binary component can have, unless there is also radiation from the other component. Thus, the"L1-point" will be unshifted and the "Roche lobe" will be the classical Roche lobe.

Abbott: In the envelope of UW CMa, the line radiation force greatly exceeds the continuous radiation force and this should be accounted for in equipotential calculations.

Rahe: You are quite right. The radiation pressure effect increases substantially if the influence of the line radiation force is taken into account. The main point is that as mentioned in Mc Cluskey and Kondo (1976, Ap.J. 208, 760), the mass flow parameters are not determined by the Roche equipotentials, but by the nature of the stellar wind emanating from the O7f star.

Underhill: In talking about the radiation pressure driving the wind, what happens to the photon's momentum?

Castor: The photon's momentum is not lost, only the direction is changed. At each scattering an impulse is given to the gas equal to the change in the vector momentum. After one scattering the photon can fly across the envelope and be going outward again before the next scattering, thus giving in each case a net outward impulse. The magnitude of momentum goes down only on account of the Doppler shift, but this effect is negligible.

Vanbeveren: I have tried to show that the conclusion of Y. Kondo and McCluskey about the shape of their critical surfaces is strictly dependent on their assumptions for the radiation force (they consider a spherical symmetric approximation). However, taking into account gravitational darkening and using the von Zeipel law, it was shown that we get total different results for the critical surface. Concerning the absorption coefficient, I really don't want to say something definite about it. In any case, I don't think that one has to use the line opacities appearing in the theory of Castor because there already a velocity gradient is present and equipotential surfaces apply to hydrostatic material.
I just want to remark that one has to be very careful with the word critical surface. A Roche lobe is totally different from a surface where the gravitational forces are balanced by the radiation force: the mode of mass loss for both processes is totally different.

Editor's Note : Dr. Yoji Kondo has requested that the following statement of his be added to this discussion: "It is very unlikely that von Zeipel's theorem is applicable to this problem. The conditions under which this theorem would be useful are almost certainly inapplicable here". (in answer to the remark of Wilson).