MASS FLOW IN INTERACTING BINARIES OBSERVED IN THE ULTRAVIOLET

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ABSTRACT

Recent satellite observations of close binary systems show that practically all binaries exhibit evidence of mass flow and that, where the observations are sufficiently detailed, a fraction of the matter flowing out of the mass-losing component is accreted by the companion and the remainder is lost from the binary system. The mass flow is not conservative. During the phase of dynamic mass flow, the companion star becomes immersed in optically-thick plasma and the physical properties of that star elude close scrutiny.

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1. BACKGROUND

Two decades ago, there was a popular myth that, when the more massive star in a close binary system evolves and fills its critical Roche equipotential surface, the gas flowing out of that star (star A) through the inner Lagrangian point is wholly accreted by its companion (star B). When the companion star that has accreted the matter, has become more massive and has evolved to fill its critical equipotential surface, matter is lost from star B back to star A. This process was dubbed conservative mass flow or, more poetically, the "dog-eats-dog" model. There was no theoretically compelling reason or observational evidence supporting such an idea but this scenario had considerable currency.

The advent of ultraviolet astronomy over the past two decades has substantially improved our understanding of the evolutionary processes in close binaries. The temperatures and densities of the gas flowing within or out of the interacting binary systems are such that the spectral signatures are most readily observable in the ultraviolet, in particular, in the resonance absorption lines of singly or multiply ionized atoms, such as Mg II, Fe II, Al III, C IV, Si IV and N V. Some metastable lines, e.g., those of Fe II and C III, have also proven valuable in deriving information on the gas densities.

Based on the ultraviolet data, gas flow is present in practically all binaries observed at high-resolution ($R = 10^4$) with the International Ultraviolet Explorer (IUE). Judging from the radial velocities of the absorption features observed, a fraction of the gas is being lost from the binary. This indicates that in addition to the gravitational force some additional force, such as the force that energizes stellar winds, is contributing to the gas flow. The evolved component in a fraction of Algol-type binaries does not seem to fill its critical Roche equipotential surface; yet the gas flow occurs. This also requires the existence of a force that drives the mass flow from the mass-losing star.

A fraction of the plasma streaming out of the mass-losing star is apparently being accreted by the companion as evidenced by the high-temperature spectral features, e.g., Si IV, C IV and N V, which are too hot for a single star of that spectral type.

2. RECENT IUE OBSERVATIONS OF TWO ALGOL-TYPE BINARIES

2.1 U Cephei

This 2.49-day period binary (B7-8 V + G8 III-IV; e.g., Batten 1974) long considered a typical Algol-type system, underwent another of its irregularly occuring transient high mass flow events during June 1988 (McCluskey, Kondo and Olson 1988). Although the mass flow outburst in 1974-5 was observed with the ultraviolet photometers onboard the Astronomical Netherlands Satellite (Kondo, McCluskey and Wu 1978), this was the first time that it was observed in the ultraviolet at a high resolution. The spectra show that the ultraviolet continuum flux decreased by factors of 1.2 to 3.0 during the greatest activity. Also, one or more narrow absorption line components with radial velocities as high as -500 km/s appeared in a number of the Mg, Fe, C, Si, Al and Zn ions. At one point, the Mg II doublet exhibited a flat-bottomed appearance with a residual intensity of about 0.3 and a Doppler width of at least 800 km/s. These spectral features indicate high velocity gas streams, mass loss from the binary and the formation of an optically-thick,

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equatorial bulge around the B-type component.

2.2 TX Ursae Majoris

This Algol-type binary (B8 V + F-K III-IV; e.g., Swensen and McNamara 1968) with a 3.06-day period has been observed with the IUE for several years. In all, 22 far-ultraviolet and 23 mid-ultraviolet high resolution spectra have been analyzed by McCluskey, McCluskey and Kondo (1988). This binary seems as active as U Cephei during its quiescent phase (Kondo, McCluskey and Stencel 1979; Kondo, McCluskey and Harvel 1981), at which time a gas stream from the G giant was seen to spiral around the B star, leaving the binary before completing a circuit around that star.

The presence of the resonance doublets of N V, C IV and Si IV in the far-ultraviolet spectra indicates an electron temperature of 10^5 K and an electron number density of 10^9 cm^{-3} with a concentration near the following hemisphere of the primary.

The absorption line strengths changed substantially from 1980-81 (Polidan and Peters 1982: Peters and Polidan 1984) to 1985 (McCluskey, Kondo and Olson 1988). Peters and Polidan did not detect the N V and C IV lines, though they were actually present weakly; those lines were quite strong in the 1985 data. The Si IV resonance lines also became significantly stronger in 1985.

3. CONCLUDING REMARKS

In addition to showing that mass flow in binaries is not wholly conservative and that a fraction of the flowing gas is accreted by the main-sequence companion, the recent results indicate that the so-called Roche-lobe overflow model probably does not adequately describe mass flow in Algol-type binaries. The question is what causes overflow since the evolutionary expansion time scale is very considerably longer than the duration of mass flow episode. It seems clear that forces other than the gravitational force are affecting the mass flow. During the phase of active mass flow, the main-sequence early-type companion to the mass-losing evolved star is covered, at least partially, by the optically-thick plasma from the late-type star.

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DISCUSSION

Chambliss asked about the absolute dimensions of R Ara. He questioned whether a normal B9 star in a system with a period of over four days would show so much evidence of interaction. Kondo replied that the most comprehensive paper on the system was still that by J. Sahade (*Astrophys. J.* **116**, 27, 1952) who made several assumptions in order to derive physical parameters, and emphasized the tentative nature of the latter. Guinan suggested that a period study might elucidate whether or not R Ara was in the rare stage of mass-transfer from the more massive component. Budding promised more news on the system later in the meeting (p.213).

Rucinski pointed out that the secondary of U Cep, a G8 III-IV star, might be very active if rotating synchronously ($P = 2^{d}.4$). He wondered if the filling in of the far UV lines might be by emission arising in the transition-layer of the secondary. Kondo and Plavec agreed that the secondary star was (relatively) too faint, by several orders of magnitude, for this to be a plausible explanation. Moreover, Plavec, pointed out that the emission region is eclipsed at primary minimum and must be near the primary star.

Peters suggested that the intensity of the UV continuum in the spectrum of TX UMa should be compared with the observations made by her group, with *IUE*, in 1980-1. She pointed out that in the spectrum of AU Mon, when the optical and UV fluxes are low, the shell and stream lines appear to be enhanced (or, alternatively, when the stellar flux is high, lines of superionization species are stronger.)

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