MASS FLOW DUE TO HEATING IN A BINARY SYSTEM: APPLICATION TO U CEPHEI

Yoji Kondo
Laboratory for Astronomy and Solar Physics, NASA/GSFC
Greenbelt, MD 20771, U.S.A.

Jerry L. Modisette
Modisette, Inc.
4223 Richmond Avenue, Houston, TX 77027, U.S.A.

Abstract

We have investigated the possibility of mass flow due to the heating of the cooler component in a close binary system. The heating may be caused by irradiation from the hotter companion or by other mechanisms such as the spacial coincidence of non-linear "g-mode" oscillations in the cooler star. The 2.4-day period binary U Cep, in which gas streaming has been observed, has been chosen for model calculations. Preliminary results show that such a heating of the lower atmosphere of the cooler star could lead to mass flow at an average rate of 10^{-9} to 10^{-7} solar mass per year without the star's necessarily filling its critical Roche surface.

1. Introduction

We recently reported our initial results (Modisette and Kondo 1980a, b) on the problem of mass flow due to the heating of the surface of the cooler component in a close binary; in those previous papers a binary system analogous to Her X-1 = HZ Her was used as a model. The source of the heating was not specified in that study but the beat of harmonics in the non-linear "g-mode" oscillations might be responsible for periodic heating in HZ Her (Wolff and Kondo 1978). We wish to report on our follow-on work since these prior publications.

2. Model

We have used U Cephei for model calculations. The reasons are partially that gas streaming observed in U Cep (Kondo, McCluskey and Stencel 1980; Kondo, McCluskey and Harvel 1981) requires a source of energy in addition to that available from the simple conversion of gravitational potential into kinetic energy in what is commonly known as Roche lobe overflow. Also, irradiation by the hotter B8

Z. Kopal and J. Rahe (eds.), Binary and Multiple Stars as Tracers of Stellar Evolution, 317–319.

https://doi.org/10.1017/S025292110010065X Published online by Cambridge University Press

star in that binary could heat the facing hemisphere of the cooler G star up to a few thousand degrees, which might provide the energy necessary for causing mass surge.

Batten's (1974) values have been adopted as the physical parameters for U Cep. That is, the mass of the B8 star is 4.2 $M_\odot$, the mass of the G5 III companion, 2.8 $M_\odot$, the radius of the B component, 2.9 $R_\odot$, the radius of the G component, 4.7 $R_\odot$, the separation of the centers of the two stars, 14.7 $R_\odot$ and the orbital period, about 2.493 days. Thus, the G star does not fill its critical Roche lobe; its radius is 70 percent of the distance to the first Lagrangian point.

If the surface temperature of the B star is 13500K and that of the G star 4700K, for the dilution factor appropriate for the above geometry, the amount of heating at the photosphere of the G star should be in the range of 1000 to 2000K, provided that the absorption of the irradiation in the photosphere of the G star is at the efficiency of 30 to 50 percent. However, our current knowledge of the ultraviolet absorptivity of the atmospheres of various type stars is rather incomplete.

The previously used theoretical program (Modisette and Kondo 1980b) was modified to enable calculations of continuous heating as well as sinusoidal heating.

3. Discussions

The results show that the continuous heating of the lower chromosphere could lead to mass surge lasting a few hundred thousand seconds. Total mass flow would depend on the density of the layer where the effective absorption of the irradiation occurs as well as on a number of other boundary conditions in the model. The rate could correspond to 10^{-9} to 10^{-7} solar mass per year. The outflow does not continue for more than a few days if the heating at the original layer remains constant. However, the opacity of the atmosphere at higher level would increase as the mass surge progresses higher; this would in turn decrease the irradiation at the original layer. If hot spots should develop on the B star as the result of the accretion of the ejected matter from the G star, this could also change the amount of irradiation from the B star. At any rate, the heating at the base of the chromosphere is likely to fluctuate.

We have thus carried out computations for the case in which the heating at the base varies in a sinusoidal fashion over the periods of 100 to a few hundred seconds. Note that non-linear oscillations could also give rise to periodic heating of the lower chromospheres. Calculations show that although the mass surge oscillates wildly at lower levels, pulses of surges move more or less continuously through the layers of large distances, say, of 1 solar radius from the photosphere. The average rate of mass flow is in the range of 10^{-9} to 10^{-7} solar mass per year. Unlike the continuous heating case, the mass surge due to the pulsed heating could continue for an apparently indefinite period. The calculations have been carried out thus far for the duration of up to 10^{6} seconds.

We have had to make a number of gross simplifications in performing these calculations. What our preliminary results show is merely what could be happening rather than what must be happening in a close binary like U Cep. Nevertheless, the disturbances at the lower atmosphere in the form of heating by its hotter companion or by non-linear oscillations could lead to significantly higher degrees of disturbances at higher levels. It has been well known that a disturbance at a higher density medium may propagate into a lower density medium increasing its amplitude. As the smaller quantity of matter tries to carry the same amount of energy, the amplitude of the disturbance must be increased. Examples of such phenomena include the breaking of waves on the beach or the cracking of a whip. Solar wind too is harnessed by propagation of the disturbances at lower atmospheres through chromosphere and corona.

The physical parameters due to Batten (1974) indicate that the G star in U Cep does not fill its Roche lobe; its radius reaches only 70 percent of the critical radius. The gas stream observed in this binary would, therefore, seem to require that there be a mechanism, other than the conversion of gravitational potential, to harness the mass flow.

According to the present results, mass flow, caused by heating, could start off long before the star fills its critical Roche lobe. When the star fills the critical equipotential surface, mass flow could be further assisted and accelerated by this process. This also means that the presence of a gas stream emanating from the cooler component in a binary system would not necessarily indicate that the cooler star has filled its critical Roche equipotential surface.

We wish to thank Jim Sewell for a very capable assistance in carrying out computer programming and calculations.

References

Batten, A.: 1974, Pub. Dom. Astrophys. Obs. 11, 191.
Kondo, Y., McCluskey, G. E., and Stencel, R. E.: 1980, Astrophys. J. 906.
Kondo, Y., McCluskey, G. E., and Harvel, C. A.: 1981, Astrophys. J. 202.
Modisette, J. L. and Kondo, Y.: 1980a, Proc. IAU Symp. No. 88, 195.
Modisette, J. L. and Kondo, Y.: 1980b, Astrophys. J. 240, 180.
Wolff, C. L. and Kondo, Y.: 1978, Astrophys. J. 219, 605.