THE PROBLEM OF MASS TRANSFER IN THE SYMBIOTIC BINARY CH CYGNI

A. Skopal
Astronomical Institute, Slovak Academy of Sciences,
059 60 Tatranská Lomnica, Czechoslovakia

Received 18 September 1987

ABSTRACT. The calculation of Roche's limit for asynchronous rotation and elliptical orbit is applied to the cool component of the symbiotic star CH Cygni. The probable value of Roche's limit of 200 R☉ agrees well with the values determined from spectrophotometric observations for the distance of CH Cygni of 500 - 600 pc. The main phenomena observed in phase of activity 1977 - 1986 are then the consequence of mass transfer from the red M6III giant due to overflowing Roche's limit. The dimensions of Roche's potential in the periastron and apoastron do not differ substantially for larger values of parameter $p = P_{orb}/P_{rot}$ ($\gtrsim 5$), and the mass transfer is not limited just to the close neighbourhood of the periastron.

ПРОБЛЕМА ПЕРЕНОСА МАССЫ В СИМБИОТИЧЕСКОЙ ДВОЙНОЙ СН ЛЕБЕДЯ. Вычисление размера поверхности Роша для несинхронного вращения и эллиптической орбиты было применено для холодного компонента симбиотической звезды СН Лебедя. Вероятная величина 200 R☉ поверхности Роша хорошо совпадает с величиной определенной из спектрофотометрических наблюдений для растояния СН Лебедя 500 - 600 пс. Главные наблюдаемые явления фазы активности 1977 - 1986 гг. являются следствием переноса массы из красного M6III гиганта перетечением поверхности Роша. Для больших величин параметра $p = P_{orb}/P_{rot}$ ($\gtrsim 5$), размеры поверхности Роша в периастре и апоастре значительно неотличаются и перенос массы не связан только с близкой окресностью периастра.

PROBLÉM PŘENOSU HMOTY V SYMBIOTICKÉ DVOJHVĚZDĚ CH CYGNI. Výpočet velikos-

© Astronomical Institute of the Slovak Academy of Sciences • Provided by the NASA Astrophysics Data System

ti Rocheovy meze pro nesynchronní rotaci a eliptickou dráhu je aplikován na chladnou komponentu symbiotické hvězdy CH Cygni. Pravděpodobná hodnota 200 R⊙ Rocheovy meze je v dobrém souhlase s hodnotou určenou ze spektrofotometrických pozorování pro vzdálenost CH Cygni 500 - 600 pc. Hlavní pozorované jevy ve fázi aktivity 1977 - 1986 jsou potom důsledkem přenosu hmoty z červeného M6III obra přetečením Rocheovy meze. Pro větší hodnoty parametru $p = P_{orb}/P_{rot}$ ($\gtrsim 5$), se rozměry Rocheova potenciálu v periastru a apoastru výrazně neliší a přenos hmoty není vázaný jen na blízké okolí periastra.

1. INTRODUCTION

The last phase of activity of the symbiotic binary CH Cygni has been observed since 1977 (Fehrenbach, 1977; Morris, 1977) and up to 1986 (Tomov et al., 1986; Tomov et al., in press). It reached its maximum in the interval 1982 - July 1984. A strong blue continuum was observed at the time (Ipatov and Yudin, 1983). The U, B, V magnitudes went up to $5^m_.5$ - $5^m_.9$ (Luud et al., 1986), the intensities of the emission components of all elements increased, e.g. (Skopal et al., in press), and rapid changes in the profiles of the absorption components of ionized metals were observed (Skopal et al., 1987). A sudden decrease in brightness by as much as 1.0 - 1.5 m_V was observed in July 1984 (Mikolajewski and Tomov, 1986), and radio outbursts and expanding bipolar jets since April 1984 (Taylor et al., 1986). Taylor et al. (1986) demonstrated that the mass loss ratio in the jets was comparable with the critical acretion ratio of an acreting white dwarf ($\sim 10^{-5}$ M⊙/yr).

The spectroscopic and photometric changes observed indicate that CH Cygni was a strongly reacting symbiotic binary during this period.

About 250 new radial velocities were obtained during this interval (Hack et al., 1986; Tomov and Luud, in press; Skopal et al., in press). Although the radial velocities display a considerable real scatter, e.g. (Skopal, in press), their slow variations reflect the orbital motions of the hot and cool component. Mikolajewski et al. (1987) and Skopal et al. (1987) determined the new elements of the spectroscopic orbit for both components, and Mikolajewski et al. (in press) only for the cool component. The long orbital period of the system of 5750 days was also proved photometrically (Mikolajewski et al., 1987); the time of periastron passage comes out at 1982, i.e.roughly in the middle of the last activity phase, and the actual orbit eccentricity is about 0.5. The semi-major axis of the orbit is then 9 AU (the sum of masses is equal to 3 (Skopal et al., 1987)). In these circumstances, Hack et al. (1986), Luud et al. (1986), Mikolajewska et al. (1987) and Mikolajewski et al. (1987) claim that the red M6III giant in CH Cygni cannot fill Roche´s limit and, therefore, they assume the mass acretion on the white dwarf takes place from the stellar wind of the cool giant. However, a precise estimate of Roche´s limit for the red giant has not been made.

The purpose of this study is to apply the calculation of the critical potential in eccentric orbits with asynchronous rotation to the orbital parameters of CH Cygni and to show the possibility of filling it by the red M6III

© Astronomical Institute of the Slovak Academy of Sciences • Provided by the NASA Astrophysics Data System

giant in a wide interval around the periastron.

2. ROCHE´S LIMIT FOR THE COOL COMPONENT IN CH CYGNI

With a view to the asynchronous rotation of the components and to the elliptical orbit, the generalized binary potential can be expressed as, e.g. (Wilson, 1979)

$$\Phi = (\Omega^2 R^2/(1+q)).(-R/r_1 - qR/r_2 - Rx/r^2 - (1+q)p^2(x^2+y^2)/2R^2), \quad (1)$$

where

$$r_2 = (x^2+y^2+z^2)^{1/2}, \quad r_1 = (r^2+2rx+r_2^2)^{1/2} \text{ and } r = R(1-e^2)/(1+\cos\nu)$$

is the instantenous distance of the star centers, ν is the proper anomaly, e the orbit eccentricity, R the principal semi-axis of the orbit, $\Omega = 2\pi/P_{orb}$ the orbital angular frequency, $q=M_2/M_1$ the mass ratio, and $p=\omega/\Omega$ the ratio of the rotational angular velocity ω and the orbital frequency. (x,y,z) are Cartesian coordinates whose origin is in the centre of the secondary component, and which rotate with the star at the constant angular velocity . Vector is perpendicular to the orbital plane and points in the direction of the z-axis. The direction of the x-axis is the same as that of the radius-vector from the centre of star 1 to star 2.

The position of the saddle point L_1 is defined as the point where all acting gravitational forces are zero, i.e. $\nabla\Phi = 0$. The partial derivatives $\partial\Phi/\partial y$ and $\partial\Phi/\partial z$ evidently vanish along the x-axis. We then obtain x_{L1} by solving the equation $\partial\Phi/\partial x = 0$, i.e.

$$(\Omega^2 R^2/(1+q)).(R/(r+x)^2 - qR/x^2 - R/r^2 - (1+q)p^2 x/R^2) = 0 \quad (2)$$

The critical equipotential plane, i.e. the equipotential containg point L_1, is defined by the solution of the equation $2\Phi - C_1 = 0$, where $C_1 = 2\Phi(x_{L1})$.

The following orbital parameters were used in applying Eq. (1) to the cool M6III giant in CH Cygni: P_{orb} = 5740 days (Mikolajewski etal., in press, average value) and e = 0.5 (Skopal et al., 1987; Mikolajewski et al., in press, average value), mass ratio $M_2/M_1 = M_{cool}/M_{hot} = 3.5$, and the sum of the component´s masses equal to 3 (Skopal et al., 1987). Unfortunately, the rotational period of the cool component is not known. Slow rotation is assumed, with a period of the order of hundreds of days. Figure 1 shows Roche´s limits for ratios p = 1 (synchronous rotation, $P_{rot} = P_{orb}$), p = 5 (P_{rot} = 1148 days) and p = 10 (P_{rot} = 574 days) in units of length of the orbit´s semi-major axis (R =9 AU = 1945 $R_\odot$). The internal sections (z = 0) correspond to the position in the periastron and the external to the position in the apoastron. Table 1 summarizes the other parameters of Roche´s limits. The dimensions of Roche´s limits are strongly affected by higher values of p ($\gtrsim$5): they decrease together with the difference of their dimensions in the periastron and apoastron. Due to the large orbital period of CH Cygni, it is reasonable to assume the ratio p = 10 - -20. The dimension of Roche´s limit then comes out about 200 $R_\odot$, and it can be filled practically at any point of the orbit. This can explain the considerab-

© Astronomical Institute of the Slovak Academy of Sciences • Provided by the NASA Astrophysics Data System

le duration of the last activity phase of CH Cygni.

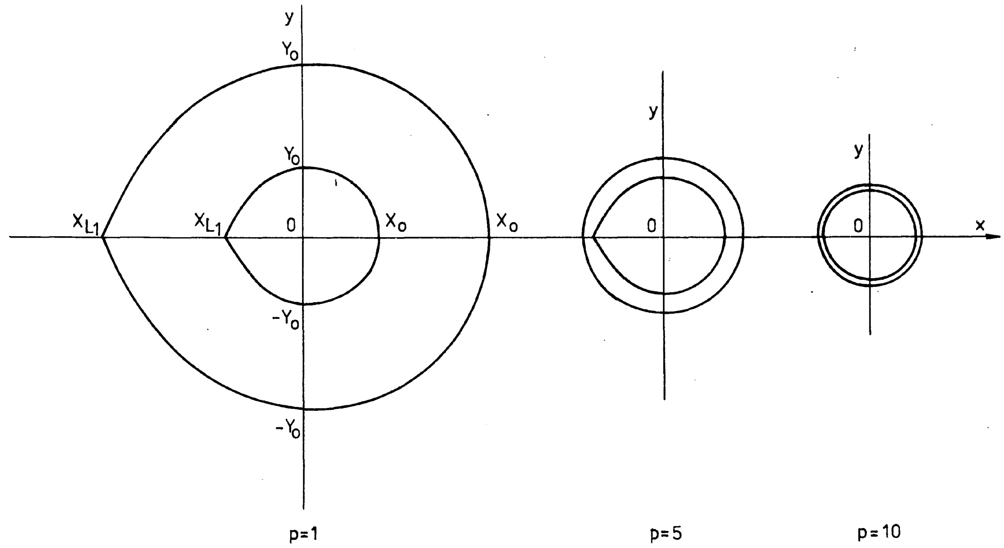

Fig. 1. Forms of Roche lobe in binary with e = 0.5, q = 3.5 for ν = 0 the(closest one), $\nu = \pi$ (the largest one) and p = 1, 5, 10.

Table 1

ν	p	$-x_{L1}$	$-C_1$	x_o	y_o	z_o	R_r
0	5	0.2743	9.0336	0.2342	0.2229	0.1896	368.8
	10	0.1933	12.8893	0.1772	0.1696	0.1293	251.5
	20	0.1242	19.6567	0.1197	0.1161	0.0828	161.0
ν_{1977}	5	0.3133	7.7762	0.3031	0.2943	0.2089	406.3
	10	0.1980	12.1185	0.1954	0.1919	0.1320	256.7
	20	0.1248	19.0308	0.1241	0.1229	0.0832	161.8
ν_{1986}	5	0.3131	7.8034	0.3015	0.2923	0.2087	405.9
	10	0.1979	12.1421	0.1950	0.1912	0.1319	256.5
	20	0.1248	19.0531	0.1241	0.1227	0.0832	161.8
π	5	0.3137	7.7316	0.3055	0.2977	0.2091	406.7
	10	0.1980	12.0789	0.1960	0.1929	0.1320	256.7
	20	0.1248	18.9928	0.1244	0.1232	0.0832	161.8

Table 1. Parameters of Roche lobes in orbit with eccentricity e = 0.5 and mass ratio q = 3.5. ν is true anomaly ($\nu_{1977} = -150^o$ and $\nu_{1986} = 143^o$), p the ratio of the orbital period of system and the rotational period of the component, x_{L1} is x-coordinate of L_1-point, x_o, y_o and z_o are coordinates of intersections of Roche lobe with coordinate axes. R_r is approximate radius of Roche lobe in units of the sun radius R⊙ (semi-major axis R = 1945 R⊙).

© Astronomical Institute of the Slovak Academy of Sciences • Provided by the NASA Astrophysics Data System

3. RADIUS AND EFFECTIVE TEMPERATURE OF THE COOL COMPONENT

Deutsch et al. (1974) derived the approximate temperature, T_{ef} = 2800 K, and luminosity, log L = 3.18 L⊙, as well as the radius, r_* = 172 R⊙, from the luminosity class and spectral type of the cool component of CH Cygni, M6III. From the distribution of energy in the spectrum, Luud and Tomov (1984) determined the physical characteristics of the cool component: T_{ef} = (2850 ± 120)K, log L = 3.84 L⊙ and r_* = (340 ± 35) R⊙ for the distance of CH Cygni of 330 pc. Recently Mikolajewski et al. (1987) estimated the radius of the cool component to be between 160 and 185 R⊙, based on the eclipse of hot component by the cool one.

Under the assumption that the energy distribution in the star´s spectrum corresponds to the radiation of an absolutely black body, the flux from the star´s surface $\mathcal{F}_{BB}(\nu) = 2\pi\int_0^1 B_\nu(T)\mu d\mu = \pi B_\nu(T)$, and thus the flux observed at distance D from the star

$$f_\nu = \pi(r_*/D)^2 B_\nu(T). \qquad (3)$$

This relation was used to determine the parameters r_*/D and T_{ef} from the spectrophotometric observation of July, 1975 (Gusev, 1977), i.e. at a time when CH Cygni displayed a practically clean M-spectrum. The observation was made in the spectral region of 330 nm - 750 nm with a resolution of 5 nm. The values of f_ν in the TiO bands were not used. The method of least squares yielded the parameters $r_*/D = (7.9 \pm 0.7)\times10^{-9}$ and T_{ef} = (2880 ± 100) K. The distance of CH Cygni was considered to be between 200 and 600 pc.,e.g. (Mikolajewska et al., 1987). For distances of 500 to 600 pc, the star´s radius comes out as 175 to 210 R⊙, and this corresponds to the probable dimensions of Roche´s limit of the giant.

The main consequence of the application given above, is the possibility of mass transfer from the red giant by overflow of Roche´s limit even in systems with a long orbital period. This mass transfer may occur within a broad neighbourhood of the periastron, depending on the ration of the orbital and rotational periods of the component considered. The large acretion ratio necessary for the formation of a massive disk and the observed bipolar jets, can be explained better by mass overflow over Roche´s limit in CH Cygni.

REFERENCES

Deutsch, A. J., Lowen, L., Morris, S. C., Wallerstein, G.: 1974, Publ. Astron. Soc. Pacific 86, 233.

Fehrenbach, Ch.: 1977, IAU Circ. No. 3102.

Gusev, E. B.: 1977, Astron. Circ. No. 944.

Hack, M., Rusconi, L., Sedmak, G., Aydin, C., Yilmaz, N.: 1986, Astron. Astrophys. 159, 117.

Ipatov, A. P., Yudin, B. F.: 1983, Pisma v Astron. Zh. 9, 421.

Luud, L., Tomov, T.: 1984, Pisma v Astron. Zh. 10, 860.

© Astronomical Institute of the Slovak Academy of Sciences • Provided by the NASA Astrophysics Data System

Luud, L., Tomov, T., Vennik, J., Ledjarv, L.: 1986, Pisma v Astron. Zh. 12,870.

Mikolajewska, J., Selvelli, P. L., Hack, M.: 1987, Astrophys. Space Sci. 131, 725.

Mikolajewski, M., Tomov, T.: 1986, Mon. Not. R. Astron. Soc. 219, 13.

Mikolajewski, M., Tomov, T., Mikolajewska, J.: 1987, Astrophys. Space Sci. 131, 733.

Mikolajewski, M., Szczerba, R., Tomov, T.: Proceedings of IAU Coll. No. 103 "Symbiotic phenomenon",(Eds. M. Friedjung, S. Kenyon and J. Mikolajewska; D. Reidel Publ. Co., Dordrecht), in press.

Morris, S., C.: 1977, IAU Circ. No. 3101.

Skopal, A., Mikolajewski, M., Tomov, T.: 1987, Astrophys. Space Sci. 131, 747.

Skopal, A.: Proceedings of IAU Coll. No. 103 "Symbiotic phenomenon", (Eds. M. Friedjung, S. Kenyon and J. Mikolajewska; D. Reidel Publ. Co., Dordrecht), in press.

Skopal, A., Mikolajewski, M., Biernikowicz, R.: Proceedings of 10th European Regional Meeting of IAU, in press.

Skopal, A., Mikolajewski, M., Biernikowicz, R.: Bull. Astron. Inst. Czechosl., in press.

Taylor, A. R., Seaquist, E. R., Mattei, J. A.: 1986, Nature, 319, 38.

Tomov, T., Mikolajewski, M., Mikolajewska, J.: 1986, Inf. Bull. Var. Stars, No. 2921.

Tomov, T., Luud, L.: Publ. Tartu Astrofiz. Obs., in press.

Tomov, T., Mikolajewski, M., Mikolajewska, J.: Proceedings of the COSPAR/IAU Symposium on the Physics of Compact Objects: Theory versus Observations, 13 - 19 July 1987, Sofia, Bulgaria, in press.

Wilson, R. E.: 1979, Ap. J. 234, 1054.

© Astronomical Institute of the Slovak Academy of Sciences • Provided by the NASA Astrophysics Data System