Mass of the white dwarf in the symbiotic binary star MWC 560

Radoslev Zamanov[1], Andreja Gomboc[2], Georgi Latev[1]
[1] Institute of Astronomy and NAO, Bulgarian Academy of Sciences, BG-1784 Sofia
[2] Faculty of Mathematics and Physics, University of Ljubljana, SI-1000 Ljubljana
rkz@astro.bas.bg; glatev@astro.bas.bg
(Research report. Accepted on 23.06.2011)

Abstract. We report an estimate of the white dwarf parameters in the symbiotic binary star MWC 560. We calculate white dwarf mass to be $M_{WD} = 0.85 - 1.0\ M_{\odot}$ and its radius to be $R_{WD} = 6900 - 5600$ km. Our estimate is derived on the basis of the observed ejection velocities and suggested connection between jet and escape velocities.
Key words: stars: binaries: close – binaries: symbiotic – stars: individual (MWC 560)

Маса на бялото джудже в симбиотичната двойна звезда MWC 560

Радослав Заманов, Андрея Гомбоц, Георги Латев

Ние докладваме една оценка на параметрите на бялото джудже в симбиотичната двойна звезда MWC 560. Изчислихме, че неговата маса е $M_{WD} = 085 - 1.0\ M_{\odot}$ и радиусът му е $R_{WD} = 6900 - 5600$ км. Оценката е направена на база на наблюдаваните скорости на изхвърляне на вещество и връзка между скоростта на джета и скоростта на освобождаване (втора космическа).

1 Introduction

MWC 560 (V694 Monocerotis) was discovered as an object with bright hydrogen lines (Merrill & Burwell 1943). It is a symbiotic binary system, which consists of a red giant and a white dwarf. The orbital period is estimated to be $P_{\rm orb} = 1931 \pm 162$ day (Gromadzki et al. 2007). Its optical spectrum shows prominent emission lines of H I, He I, Fe II, Ti II superimposed on the absorption features of an M type giant (Chentsov et al. 1997; Tomov & Kolev 1997). The long term light curves (Luthardt 1991, Doroshenko et al. 1993) show that during the last century the star brightness varied in the range $m_{\rm B} = 11.0 - 12.5$, with one outburst in 1990, when it achieved $m_{\rm B} \approx 9.5$.

The most spectacular features of this object are the collimated ejections of matter (jets) with velocities of up to ~ 6000 km s^{-1} (Tomov et al. 1992) and the resemblance of its emission line spectrum to that of the low-redshift quasars (Zamanov & Marziani 2002). Astrophysical jets are seen in systems ranging from black holes in X-ray binaries, to pre-main-sequence stars and active galactic nuclei. Jets are observed in a few symbiotic stars, however they have never been detected in cataclysmic variables, probably due to lower mass-accretion rate (Hillwig, Livio, & Honeycutt 2004; Soker & Lasota 2004).

MWC 560 is practically a SS 433 type object with white dwarf (Iijima 2002). The object is visible almost pole-on. This makes it difficult to obtain the orbital parameters using conventional methods like the radial velocity variations, eclipses, etc.

Our aim here is to obtain an estimate of the white dwarf mass, following the findings of Livio (1998) for the velocities of astrophysical jets.

2 System parameters

Meier et al. (1996) classified the cool component of MWC 560 as an M5III-M6III giant. Mürset & Schmid (1999) give M5.5III - M6III as its stellar type. The jet ejections in MWC 560 are along the line of sight and the system is seen almost pole-on, $i < 16°$ (Schmid et al. 2001).

On the basis of the theory of tidal interaction in binaries and measurement of the projected rotational velocity of the red giant, Zamanov et al. (2010) calculated that the orbit should be highly eccentric, with $e \sim 0.7$. This agree with the suggestions of Gromadzki et al. (2007) that the observed photometric variability of MWC 560 is connected with high orbital eccentricity and Roche lobe overflow at periastron.

3 Mass and radius of the white dwarf

Until now, the mass of the white dwarf has not been estimated. Arrieta et al. (2005) assumes a standard mass of the white dwarf $M_{\rm wd} = 0.6$ M$_\odot$. Schmid et al. (2001) and Gromadzki et al. (2007) assumes $M_{\rm wd} = 0.5$ M$_\odot$.

To estimate the mass of the white dwarf in MWC 560, we suppose that the outflow velocity $v_{\rm ej}$ corresponds to the escape velocity at the place where the outflow originates. This is a general picture for almost all jets (Livio 1997, 1998). The second equation we use is the mass-radius relation for white dwarfs.

On Fig.1 we plot three relations between V_{esc} on white dwarf surface and $M_{\rm wd}$. They are calculated using: (i) Eggleton's zero-temperature mass-radius relation as quoted by Verbunt & Rappaport (1988) – dashed line; (ii) the relation based on observations of non-magnetic white dwarfs from Sloan Digital Sky Survey (Madej et al. 2004) – dotted line; (iii) mass-radius relation for ^{12}C magnetic white dwarfs (Suh & Mathews 2000) – (red) solid line. The three lines are close to each other and our results practically do not depend which one we will use.

We introduce parameter $\alpha \approx 1$ in:

$$v_{\rm ej} = \alpha \, v_{\rm esc}, \tag{1}$$

where $v_{\rm esc}$ is the escape velocity from ejection radius $R_{\rm ej}$:

$$v_{\rm esc} = \sqrt{\frac{2GM_{\rm wd}}{R_{\rm ej}}}$$

and parameter β:

$$R_{\rm ej} = \beta \, R_{\rm wd}. \tag{2}$$

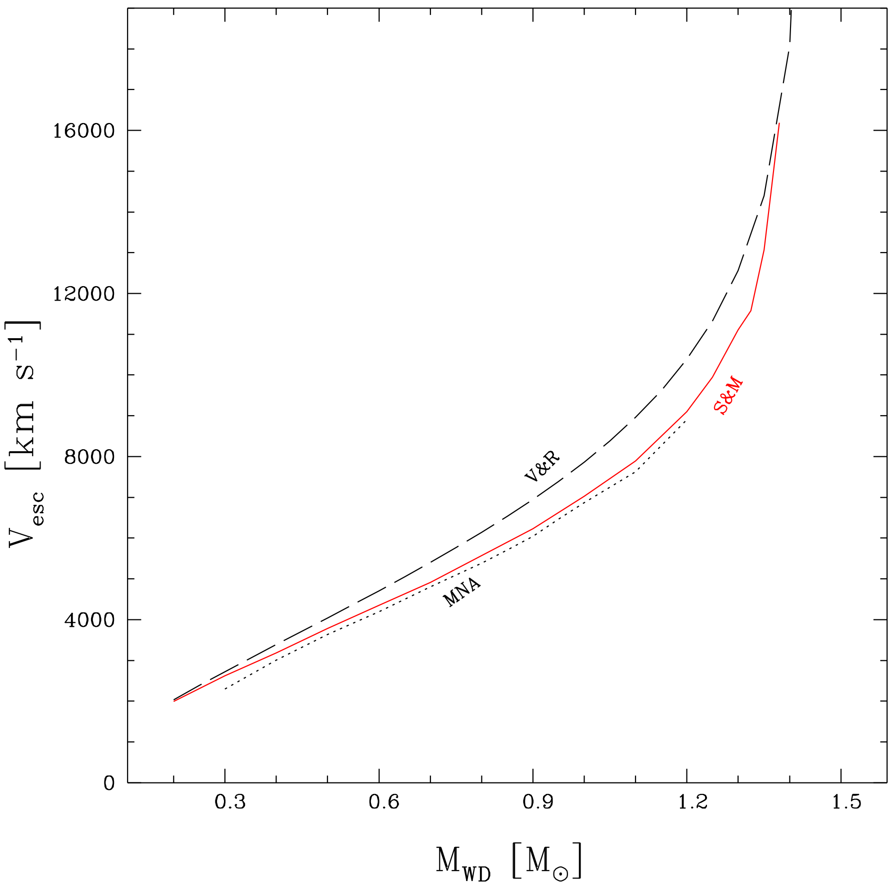

Fig. 1. V_{esc} on the WD surface versus white dwarf mass. The (red) solid line is calculated following Suh & Mathews(2000), dotted line – Madej et al.(2004), dashed line – Eggleton's relation as quoted in Verbunt & Rappaport 1988.

Using this notation, we can express:

$$v_{\rm ej} = \frac{\alpha}{\sqrt{\beta}} \sqrt{\frac{2GM_{\rm wd}}{R_{\rm wd}}}. \tag{3}$$

Following Livio (1997, 1998), α should be ≈ 1 - we assume $\alpha = 1.0 \pm 0.05$ - and β must be ≥ 1.0 (no ejection can originate under the white dwarf surface).

The jet ejections in MWC 560 are almost along the line of sight and are visible as large blue-shifts in the broad absorption components in the Balmer

Table 1. The ratio $\frac{M_{\rm wd}}{R_{\rm wd}}$ in units of kg m^{-1} for a range of values of $v_{\rm ej}, \alpha, \beta$:

$v_{\rm ej}$ [km s^{-1}]	$\alpha = 1.05$ $\beta = 1.0$	$\alpha = 1.05$ $\beta = 1.1$	$\alpha = 0.95$ $\beta = 1.0$	$\alpha = 0.95$ $\beta = 1.1$
6300	$2.7 \cdot 10^{23}$	$3.0 \cdot 10^{23}$	$3.3 \cdot 10^{23}$	$3.6 \cdot 10^{23}$
6000	$2.45 \cdot 10^{23}$	$2.7 \cdot 10^{23}$	$3.0 \cdot 10^{23}$	$3.3 \cdot 10^{23}$

Table 2. The ratio $\frac{M_{\rm wd}}{R_{\rm wd}}$ and $R_{\rm wd}$ for different values of $M_{\rm wd}$ calculated following Madej et al. 2004.

$M_{\rm wd}$ [M$_\odot$]	0.3	0.4	0.5	0.6	0.7	0.8	0.85	0.9	0.95	1.0	1.1	1.2
$R_{\rm wd}$ [km]	15000	11700	10000	9000	8000	7300	6900	6500	6000	5600	5000	4000
$\frac{M_{\rm wd}}{R_{\rm wd}}$ [10^{22} kg m^{-1}]	4.0	6.8	10	13	17.5	22	24	28	31.7	36	44	60

lines (Shore et al. 1994; Stute 2006). More than 50 discrete ejections have been observed up to now (Tomov et al. 1990; Buckley 1992, Iijima 2002). Their observed velocities are from a few hundred to a few thousand km s^{-1}. The fastest ejections should originate close to the white dwarf surface ($\beta \approx 1$, see Eq. 3) and we assume $\beta \approx 1.0 - 1.1$ for the highest observed ejection velocity.

The maximal observed velocity of the ejection in MWC 560 is about 6300 km s^{-1}. This value is calculated from the blue edge in Hβ absorption observed on 14 March 1990 (Tomov et al. 1990; Tomov & Kolev 1997) and probably corresponds to the escape velocity close to the surface of the white dwarf. Taking also into account the range of possible values for the maximal $v_{\rm ej}$ to be between 6000 kms^{-1} and 6300 kms^{-1} (the range corresponds to about a 1σ error), we obtain possible values for the ratio $\frac{M_{\rm wd}}{R_{\rm wd}}$ presented in Table 1. On the other hand, using Fig. 2 in Madej et al. (2004) (we get similar results also by using Suh & Mathews 2000; Provencal et al. 1998; Panei et al. 2000) we can determine the ratio $\frac{M_{\rm wd}}{R_{\rm wd}}$ for different $M_{\rm wd}$. Results are presented in Table 2. Comparing values in Table 1 and Table 2 we find that the possible range of white dwarf mass is between $M_{\rm wd} = 0.85$ M$_\odot$ and $M_{\rm wd} = 1.0$ M$_\odot$ with radius of the white dwarf between $R_{\rm wd} = 6900$ km and $R_{\rm wd} = 5600$ km, respectively.

Schmid et al. (2001) calculated for the hot component luminosity $L_{\rm hc} = 1000$ L$_\odot$ at the time of their spectral observations November 1998 – January 1999. This value (using $M_{\rm wd} \approx 0.9\, M_\odot,\ R_{\rm wd} \approx 6500\, km$) will correspond to a mass accretion rate $\dot{M}_{acc} \approx 3.3 \times 10^{-7}\, M_\odot\, yr^{-1}$. Using the Kepler's third law (and mass of the red giant ~ 2 M$_\odot$), we calculate the binary separation to be $a \approx 4.3$ a.u.

Conclusion

We estimate the mass of the white dwarf in MWC 560 as $M_{\rm wd} = 0.85 - 1.0\ {\rm M}_{\odot}$ (1σ error), and its radius $R_{\rm wd} = 5600 - 6900$ km.

References

Arrieta, A., Torres-Peimbert, S., & Georgiev, L. 2005, ApJ, 623, 252
Buckley, D. A. H. 1992, *in* Evolutionary Processes in Interacting Binary Stars, ed. Y. Kondo, R. F. Sistero, R. S. Polidan IAU Symp 151, 421
Chentsov, E. L., Klochkova, V. G., & Mal'Kova, G. A. 1997, Bull. Special Astrophys. Obs., 43, 18
Doroshenko, V. T., Goranskij, V. P., & Efimov, Y. S. 1993, IBVS, 3824
Gromadzki, M., Mikołajewska, J., Whitelock, P. A., Marang, F. 2007, A&A, 463, 703
Hillwig, T., Livio, M., & Honeycutt, R. K. 2004, PASP, 116, 397
Iijima, T. 2002, A&A, 391, 617
Livio, M. 1997, in Accretion Phenomena and Related Outflows, ed. Wickramasinghe, D. T., Bicknell, G. V., & Ferrario, L., ASP Conf. Ser. 121, 845
Livio, M. 1998, in Wild Stars in the Old West, ed. Howell, S., Kuulkers, E., & Woodward, C., ASP Conf. Ser., 137, 264
Luthardt, R. 1991, Information Bulletin on Variable Stars, 3563, 1
Madej, J., Należyty, M., & Althaus, L. G. 2004, A&A, 419, L5
Meier, S. R., Rudy, R. J., Lynch, D. K., et al. 1996, AJ, 111, 476
Mürset, U., & Schmid, H. M. 1999, A&AS, 137, 473
Merrill, P. W., & Burwell, C. G. 1943, ApJ, 98, 153
Michalitsianos, A. G., Perez, M., Shore, S. N., et al. 1993, ApJ, 409, L53
Panei, J. A., Althaus, L. G., & Benvenuto, O. G. 2000, A&A, 353, 970
Provencal, J. L., Shipman, H. L., Hog, E., & Thejll, P. 1998, ApJ, 494, 759
Schmid, H. M., Kaufer, A., Camenzind, M., et al. 2001, A&A, 377, 206
Shore, S. N., Aufdenberg, J. P., & Michalitsianos, A. G. 1994, AJ, 108, 671
Soker, N., & Lasota, J.-P. 2004, A&A, 422, 1039
Stute, M. 2006, A&A, 450, 645
Suh, I.-S., & Mathews, G. J. 2000, ApJ, 530, 949
Tomov, T., Kolev, D., Georgiev, L., et al. 1990, Nature, 346, 637
Tomov, T., Zamanov, R., Kolev, D., et al. 1992, MNRAS, 258, 23
Tomov, T., & Kolev, D. 1997, A&AS, 122, 43
Verbunt, F., & Rappaport, S. 1988, ApJ, 332, 193
Zamanov, R., & Marziani, P. 2002, ApJ, 571, L77
Zamanov, R. K., Gomboc, A., Stoyanov, K. A., & Stateva, I. K. 2010, AN, 331, 282