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An orbital period analysis of the dwarf novae OY Carinae

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HIGHLIGHTS

- Twelve new primary times of OY Car are obtained.
- The *O–C* curve of OY Car shows a downward parabolic variation and a cyclic change.
- We attempted to apply three mechanisms to explain the orbital period decrease for *O–C* diagram.
- There may be a third body that a critical substellar object between brown dwarf and giant planet.

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ABSTRACT

By using our twelve new *CCD* times of light minimum of OY Carinae (OY Car) together with those collected from the literature, it is found that the *O–C* curve of OY Car shows a downward parabola with an amplitude of 27.8 s and a cyclic change of a period 14.0 yr. The period decrease is opposite to the hypothesis of mass transfer, and it cannot be explained by angular momentum loss via gravitational radiation. The Rappaport et al. (1983)'s magnetic braking (MB) prescription is adopted to explain the observed orbital period decrease. The cyclic change of period is analyzed with the light travel-time effect that originates from gravitational influence of a third body. The mass of the third star is determined to be $M_3 sini' = 0.008097(\pm 0.000014)\ M_\odot = 8.48(\pm 0.02)\ M_{Jup}$, suggesting that it may be a critical substellar object between brown dwarf and giant planet. If the orbital inclination of the third body equals 90°, the distance between the third body and the mass centre of the whole system is about $6.18(\pm 0.45)$ AU.

1. Introduction

OY Car is one of the SU UMa subclass of eclipsing dwarf novae whose orbital inclination is high enough ($i = 83^\circ.3 \pm 0^\circ.2$) to display distinguishable features of ingress and egress contact phases for the accretion disc, white dwarf and bright spot in light curve. It has a short orbital period of about 1.51 h (Vogt et al., 1981) and was first discovered by Vogt et al. (1981). The Eclipsing dwarf novae offer the best opportunity for studying its geometric structure and system parameters (Ritter, 1980; Vogt et al., 1981; Bailey and Ward, 1981; Sherrington and Jameson, 1982; Berriman, 1984; Cook, 1985; Schoembs, 1987; Wood et al., 1989).

The most direct photometric evidence for mass transfer between components in a binary system is the orbital period change. Some ephemerides for OY Car have been published (Vogt et al., 1981; Cook, 1985; Wood et al., 1989; Greenhill et al., 2006). In 1985 Cook believed that the orbital period of OY Car was decreasing on an evolutionary time-scale of 2×10^7 yr. However Wood et al. (1989) showed that there is no evidence for a decreasing period; and so did Pratt et al. (1999) based on an ephemeris over 19 yr. Recently; Giampapa and Liebert (1986) gave a more detailed analyses which indicates that the orbital period is decreasing rather than constant. In addition their work suggested that the orbital period of OY Car may include cyclical changes of about 35 ± 3.5 yr; which they explained by solar-cycle-type magnetic activity in the secondary star.

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From what has been introduced above, it would be reasonable to believe that the orbital period of OY Car is changing over time. In this paper, twelve new light minima of OY Car from our observations are presented in the Section 2. And in Section 3 an analysis the *O*—*C* for OY Car is given. The discussions and conclusions of the possible mechanisms for the orbital period changes are presented in Sections 4 and 5.

2. Photometric observations

OY Car was monitored from November 2008 to November 2013 with the 0.6 m Helen Sawyer Hogg telescope and the 2.15 m Jorge Sahade telescope at Complejo Astonomico E1 Leoncito (CASLEO), San Juan, Argentina. The CH250 *CCD* camera with a PM512 chip and the Apogee Alta U8300 *CCD* camera with Kodak KAF8300 chip, which are attached to the 0.6 m Helen Sawyer Hogg telescope, were used on 2008 Nov. 28, Dec 20 and 23, and 2009 Jan. 14. Also the Apogee Alta U8300 *CCD* camera with the Kodak KAF8300 chip and the Roper Scientific, Versarray 1300B *CCD* camera, which are attached to the 2.15 m Jorge Sahade telescope, were used on 2013 Apr. and Nov.

During the observations, no filter were used. Differential photometry was performed, with a nearby, bright, non-variable comparison star. The minima were obtained by fitting a cubic polynomial curve to the deepest part of the eclipses. An eclipse profile is shown in Fig. 1. It can be seen that the distinguishable feature are that both the white dwarf and the hotspot are eclipsed by the red dwarf. The twelve new *CCD* times of mid-eclipse of OY Car are listed in Table 1.

3. The analysis of the orbital period change

Earlier times of mid-eclipse of OY Car were published by a few authors (Vogt et al., 1981; Schoembs and Hartmann, 1983; Cook, 1985; Schoembs, 1987; Wood et al., 1989; Horne et al., 1994; Pratt et al., 1999; Greenhill et al., 2006). The $(O\text{—}C)_1$ values of available minimum times were calculated with the linear ephemeris derived by Cook (1985):

$$Min.I(HJD) = 2443993.553266(12) + 0.^{d}06312092138(74) \times E, \quad (1)$$

where 2443993.553266 is the initial epoch and 0.06312092138 d is the orbital period. The corresponding $(O\text{—}C)_1$ based on the published data and our observations are shown in Fig. 2 since the year of 1979. Cook (1985) also obtained the following quadratic ephemeris:

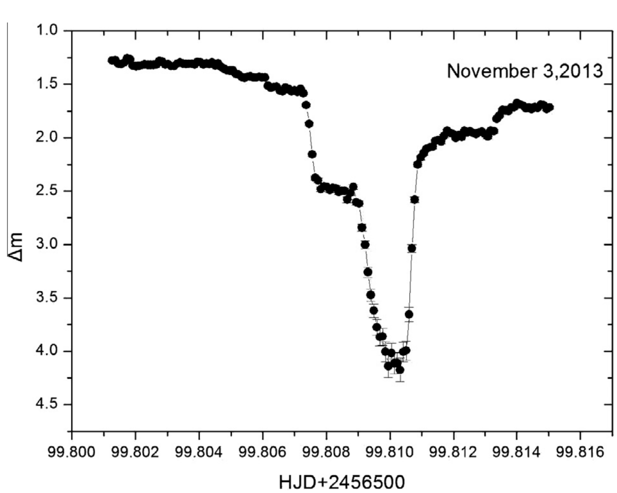

Fig. 1. Light curve of OY Car in N band obtained by using the 2.15-m Jorge Sahade telescope on 2013 November 3. The features of ingress and egress contact phase for accretion disc, white dwarf and bright spot in light curve are distinctly identifiable.

Table 1
New CCD times of light minimum of OY Car.

HJD (d)	Method	E(cycle)	O—C(d)	Error (d)	Filters
2454798.84360	CCD	171184	−0.00147	0.00005	N
2454820.80940	CCD	171532	−0.00175	0.00050	N
2454823.71310	CCD	171578	−0.00161	0.00050	N
2454845.67920	CCD	171926	−0.00160	0.00050	N
2455158.69570	CCD	176885	−0.00203	0.00050	N
2455159.70540	CCD	176901	−0.00180	0.00005	N
2455889.82573	CCD	188468	−0.00225	0.00005	N
2456033.48917	CCD	190744	−0.00252	0.00005	N
2456395.67701	CCD	196482	−0.00264	0.00005	N
2456396.56072	CCD	196496	−0.00265	0.00005	N
2456599.81010	CCD	199716	−0.00317	0.00005	N
2456601.82997	CCD	199748	−0.00317	0.00005	N

$$Min.I(HJD) = 2443993.553216(17) + 0.^{d}0631209352(39) \times E - 5.3(1.5) \times 10^{-13} \times E^2, \quad (2)$$

The quadratic term reveals a period decrease at a rate of $\dot{P} = -1.06 \times 10^{-13}$. However, the later ephemeris published by Wood et al. (1989) and Pratt et al. (1999) showed that there was not much evidence for a decreasing period. Until recently, based on the data over 26 yr, Greenhill et al. (2006) presented the ephemeris in two modes: the quadratic mode and a combination of a linear variation and a cyclic change, respectively. The ephemeres of these modes are listed as follows: For the quadratic mode:

$$HJED = 2443993.553813 + 0.0631209343 \times E - (1.47 \times 10^{-13}) \times E^2, \quad (3)$$

For the sinusoidal mode:

$$HJED = 2443993.55406 + 0.0631209126 \times E - (5.3 \times 10^{-4}) \times \sin\frac{2\pi(E - 1.7 \times 10^{-4})}{2 \times 10^5}, \quad (4)$$

This result also reveals that the orbital period was decreasing.

To fit the $(O\text{—}C)_1$ curve, a combination of a downward parabolic variation and a cyclic change is required (solid line in the upper panel in Fig. 2), indicated by the:

$$\begin{aligned}(O\text{—}C)_1 = & -0.000321(\pm 0.000014) + 1.09(\pm 0.05) \times 10^{-8} \times E \\ & - 1.19(\pm 0.03) \times 10^{-13} \times E^2 \\ & + 0.000322(\pm 0.000012) \sin[0^{\circ}.01395(\pm 0^{\circ}.00005) \\ & \times E + 31^{\circ}.64(\pm 0^{\circ}.06)],\end{aligned} \quad (5)$$

which suggests a cyclic change with a small amplitude of 27.8 s and a period of 14.0 yr. The quadratic term in equation 5 indicates a decrease at a rate of $\dot{P} = -3.77(\pm 0.15) \times 10^{-12}$. In Fig. 2, the dashed line in the upper panel refers to the linear period decrease and the solid line represents the combination of the linear decrease and the cyclic change.

4. Discussion

4.1. The secular orbital period decrease

It is thought that secular orbital period decrease of OY Car is possibly caused by three mechanisms simultaneously: the mass transfer between the components, the gravitational radiation and the magnetic braking. Thus the decrease rate of the orbital period can be described as

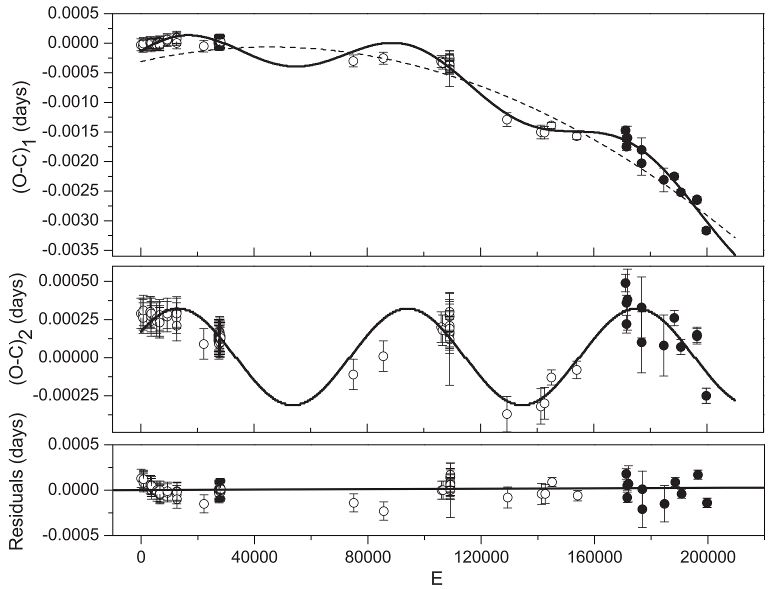

Fig. 2. The $(O-C)_1$ of OY Car are fitted in the upper panel according to Eq. (5). The solid line in the upper panel refers to a combination of a downward parabolic and cyclic change. The dashed line represents only the downward parabolic variation that reveals a continuous decrease in the orbital period. The $(O-C)_2$ values with respect to the quadratic part of equation (5) are displayed in the middle panel where a cyclic change can be seen more clearly. The open circles and solid circles denote the data in literature and in our observation respectively. After both the downward parabolic change and the cyclic variation were removed, the residuals are plotted in the lowest panel.

$$\dot{P} = \dot{P}_{GR} + \dot{P}_{MT} + \dot{P}_{MB}, \tag{6}$$

where $\dot{P}_{GR}$, $\dot{P}_{MB}$, $\dot{P}_{MT}$ are the orbital period change rates deduced by gravitation radiation, magnetic braking and mass transfer, respectively. First, The mass transfer rate can be known from the mass injection rate of the bright spot on the accretion disk. The mass injection rate is roughly $5 \times 10^{-11}\ M_\odot\ yr^{-1}$ (Wood et al., 1989). It is assumed that all the transferred mass are injected into the hotspot, so the mass transfer rate should be equal to the mass injection rate. Therefore the mass transfer rate of $\dot{M} = 5 \times 10^{-11}\ M_\odot\ yr^{-1}$ can lead to an orbital period change of $\dot{P}_{MT} = +3.32 \times 10^{-13}$. Since the system consists of a less massive donor star (red dwarf $\sim 0.07\ M_\odot$) and a more massive gainer star (white dwarf $\sim 0.68\ M_\odot$), the orbital period should increase rather than decrease. Secondly, For a binary system, General Relativity predicts that (Landau and Lifschitz, 1958)

$$\frac{\dot{J}_{GR}}{J} = -\frac{32G^3}{5c^2} \times \frac{M_1 M_2 (M_1 + M_2)}{a^4}, \tag{7}$$

where a, c and $\dot{J}_{GR}$ are the separation of the binary, velocity of light and the angular momentum loss rate caused by gravitational radiation, respectively. The system parameters of OY Car published by Wood et al. (1989) are used to calculate the angular momentum loss. So the orbital period change rate deduced by gravitational radiation is $\dot{P}_{GR} = -1.14 \times 10^{-13}$, and this result is smaller by an order of magnitude than the observed orbital period decrease. Thirdly, Some of the most widely used MB prescriptions have been provided by Verbunt and Zwaan (1981), Rappaport et al. (1983), Kawaler (1988), Mestel and Spruit (1987), Andronov et al. (2003) and Ivanova and Taam (2003). However, how to choose the most suitable model for OY Car is difficult. Fortunately, in the Fig. 2 of Knigge et al. (2011), an important comparison of MB prescriptions is given. From this careful analysis, we will adopt the prescription of the Rappaport et al. (1983) in this paper. Its strength and shape can be controlled by varying the normalization and the power-law index γ. We choose to parameterize the angular momentum loss rates due to MB as

$$\dot{J}_{MB} = -3.8 \times 10^{-30} M_2 R_\odot^4 \left(\frac{R_2}{R_\odot}\right)^\gamma \Omega^3 \quad dyn\ cm, \tag{8}$$

where R_2, γ are the radius of secondary and magnetic braking index ($0 \leqslant \gamma \leq 4$), respectively. Thus the orbital period change caused by magnetic braking can be calculated by

$$\frac{\dot{P}_{MB}}{P} \approx -1.4 \times 10^{-6}\ (\mathrm{yr}^{-1}) \frac{M^{1/3} R_2^\gamma}{M_1 P^{10/3}}, \tag{9}$$

where M, M_1, R_2 are the dimensionless quantity. The parameters of OY Car published by Wood et al. (1989) are used to calculate the magnetic braking that causes on orbital period decrease. As a result, the decrease rate is

$$\dot{P}_{MB} = \begin{cases} -8.11 \times 10^{-11} & \gamma = 0 \\ -1.03 \times 10^{-11} & \gamma = 1 \\ -1.31 \times 10^{-12} & \gamma = 2 \\ -1.66 \times 10^{-13} & \gamma = 3 \\ -2.11 \times 10^{-14} & \gamma = 4 \end{cases} \tag{10}$$

So the orbital period change rate deduced for magnetic braking is $\dot{P}_{MB} = -2.11 \times 10^{-14}$ to -8.11×10^{-11}. Clearly, the decrease rates have huge differences with different magnetic braking index.

Based on the above calculation, the period change rate caused by the mass transfer, gravitational radiation and magnetic braking together is -8.09×10^{-11} to 1.97×10^{-13}. Obviously, the observed orbital period decrease of $\dot{P} = -3.77(\pm 0.15) \times 10^{-12}$ falls into this range (i.e. $1 \leqslant \gamma \leq 2$).

It can be seen that the mass transfer and gravitational radiation can not explain the period decrease of OY Car at all. Thus, the angular momentum loss caused by magnetic braking appears to play a key role in the decrease of orbital period. However, there is a critical problem. In the CV standard model, when a donor star becomes fully convective, the magnetic braking stops. Since the secondary of OY Car is a fully convective M6V-type star, there should be no magnetic braking. Without the magnetic braking, the mass transfer and gravitational radiation can only lead to the increase of period. The reason for the observed decrease of period can not be the above three mechanisms. One possible reason is that the observed downward parabolic change may be simply a part of a long-period cyclic variation.

At some level, however, it is known for a long time that the CV standard model may not be entirely correct. After all, fully convective stars do display all aspects of stellar activity, from variability to emission line, ultraviolet, X-ray, and radio emission (Giampapa and Liebert, 1986; Stern et al., 1994; Linsky et al., 1995; Hodgkin et al., 1995; Fleming et al., 1995; Delfosse et al., 1998). Thus there is little question that fully convective stars are capable of generating significant magnetic fields (Knigge et al., 2011). In other words, the fully convective stars are also expected to generate magnetic braking strong enough to cause the substantial change of angular momentum, and this idea is supported by some observational evidence (Reiners and Basri, 2008, 2009, 2010; Donati, 2008; Morin et al., 2010).

So far, the results discussed here are just a possibility, and it is important to seek more credible evidence for the view of Knigge et al. (2011) in the future.

4.2. Cyclic oscillation

A prominent feature in the $O-C$ diagram of OY Car is the sinusoidal variation with a period of 14.0 yr. The sinusoidal curve in the middle panel of Fig. 2 could indicate one of two things: either there is a third star in the system, or there is significant magnetic activity. Greenhill et al. (2006) pointed out that the modulation could be due to solar-cycle-type magnetic activity in the donor star. As for the magnetic activity, this is usually attributed to the mechanism of Applegate (1992). In this mechanism, the changes in the inner structure of the cool component star during the magnetic activity cycles will result in the variation of the orbital period through spin–orbital coupling. However, the secondary of OY Car is a fully convective M6V-type star, Applegates mechanism in such cool stars is generally too feeble to explain the observed amplitudes of variation (Qian et al., 2012, Dai et al., 2012, Brinkworth et al., 2006 etc.). Therefore, we attempted to interpret the periodic the change of $(O-C)_2$ residuals with a light-time effect due to an invisible third star in the system (Irwin, 1952; Borkovits and Hegedues, 1996). The variation of the $(O-C)_2$ curve suggests that the eccentricity of orbit of the tertiary component is near to zero. The projected radius of the orbit of the eclipsing pair rotating around the barycentre of the triple system was computed with the equation

$$a'_{12}sini' = A_3 \times c, \tag{11}$$

where A_3 is the amplitude of the $O-C$ oscillation and c is the velocity of light, thereby $a'_{12}sini' = 0.056(\pm0.004)$ AU. The mass function of the third body $f(m)$, can then be estimated by the formula,

$$f(m) = \frac{4\pi^2}{GP_3^2}(a'_{12}sini')^3 = \frac{(M_3 sini')^3}{(M_1 + M_2 + M_3)^2}, \tag{12}$$

where G is the gravitational constant and P_3 is the period of $(O-C)_2$ oscillation. Thus the mass function $f(m) = 9.12(\pm1.01)\times 10^{-7}\,M_\odot$ and the mass $M_3 sini' = 0.008097(\pm0.000014)\,M_\odot = 8.48(\pm0.02)\,M_{Jup}$. If the orbital inclination of the third component in this triple system is larger than $35^\circ.3$, the mass of tertiary component is $M_3 \le 0.014\,M_\odot$ (the lower limit of brown dwarf). Hence it should be a giant planet with 60.8 percent probability, and a brown dwarf with 39.2 percent probability (If the Angle distribution is uniform). So the mass of this third body implies that it may be a critical substellar object between brown dwarf and giant planet. The parameters of the third star are shown in Table 2. When the orbital inclination equals 90°, the distance between the third body and the mass centre of triple system is about $6.18(\pm0.45)$ AU, which is over four orders of magnitude larger than the binary separation. Thus, this third body can have survived in the CE (common envelope) evolution of the parent binary.

Table 2
The orbital parameters of the third body in OY Car.

Parameters	Value and uncertainty	Unit
Period (P_3)	14.0 ± 0.1	yr
Eccentricity (e_3)	0	
Amplitude (A_3)	27.8 ± 0.2	s
$a_3(i' = 90^\circ)$	6.18 ± 0.45	AU
$M_3 sini'$	8.48 ± 0.02	M_{Jup}
$f(m)$	$9.12 \pm (1.01)\times10^{-7}$	$M_\odot$

5. Conclusions

From our photometry, 12 new primary times of the short-period eclipsing dwarf novae OY Car are obtained. Based on the new *CCD* data and those published by other authors, a new $O-C$ diagram of OY Car has been made, and a detailed orbital period analysis indicates that a significant sinusoidal variation with a period of about 14.0 yr and a secular orbital period decrease with a rate of $-3.77(\pm0.15) \times 10^{-12}$. We attempted to apply three mechanisms to explain the orbital period decrease for $O-C$ diagram. We considered the mechanism of mass transfer causing the orbital period decrease. Since the system consist of a less massive donor star and a more massive gainer star, we would expect the orbital period to increase rather than decrease. Gravitational radiation loss to explain the observed change. The Rappaport et al. (1983) prescription to calculate the orbital period change caused by magnetic braking found to be able to explain the observed period decrease. However, according to the CV standard model, a donor star of 0.07 $M_\odot$ should not have magnetic braking. It is therefore possible that the observed downward parabolic change is simply a part of a long-period cyclic variation.

On the other hand, recently, a key view that fully convective donors below the period gap are capable of generating significant magnetic fields and can produce MB strong enough was presented by Knigge et al. (2011). This idea is supported by some observational evidence (Reiners and Basri, 2008, 2009, 2010; Donati, 2008; Morin et al., 2010), and our calculation is consistent with this possibility.

For the cyclic variation of the $(O-C)_2$ curve in the middle panel of Fig. 2, two plausible mechanisms, that magnetic activity cycles and light travel-time effect, are considered. The former mechanism is generally too feeble to explain the observed amplitude. Based on the analysis of the light travel-time effect, a giant planet with 60.8 percent probability and a brown dwarf with 39.2 percent as a third component of the system can be explored. The third star may be a critical substellar object between brown dwarf and giant planet.

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References

Andronov, N., Pinsonneault, M., Sills, A., 2003. ApJ 582, 358.
Applegate, J.H., 1992. ApJ 385, 621.
Bailey, J., Ward, M., 1981. MNRAS 17, 23.
Berriman, Graham, 1984. MNRAS 207, 783.
Borkovits, T., Hegedues, T., 1996. Astrophys. Space Sci. 120, 63.
Brinkworth, C.S., Marsh, T.R., Dhillon, V.S., Knigge, C., 2006. MNRAS 365, 287.
Cook, M.C., 1985. MNRAS 215, 211.
Dai, Z.-B., Qian, S.-B., Fernandez Lajus, E., Baume, G.L., 2012. MNRAS 409, 1195.
Delfosse, X., Forveille, T., Perrier, C., Mayor, M., 1998. A&A 331, 581.
Donati, J. et al., 2008. MNRAS 390, 545.
Fleming, T.A., Schmitt, J.H.M.M., Giampapa, M.S., 1995. ApJ 450, 401.

Giampapa, M., Liebert, J., 1986. APJ 305, 784.
Greenhill, J.R., Hill, K.M., Dieters, S., Fieberg, K., Howlett, M., Meijers, A., Munro, A., Senkbeil, C., 2006. MNRAS 372, 1129.
Hodgkin, S.T., Jameson, R.F., Steele, I.A., 1995. MNRAS 274, 869.
Horne, K., Marsh, T.R., Cheng, F.H., Hubeny, I., Lanz, T., 1994. APJ 426, 294.
Irwin, J.B., 1952. ApJ 116, 211.
Ivanova, N., Taam, R.E., 2003. ApJ 599, 516.
Kawaler, S.D., 1988. ApJ 333, 236.
Knigge, C., Baraffe, I., Patterson, J., 2011. APJS 194, 28.
Landau, L., Lifschitz, E., 1958. The Classical Theory of Fields. Pergamon, Oxford.
Linsky, J.L., Wood, B.E., Brown, A., Giampapa, M.S., Ambruster, C., 1995. ApJ 455, 670.
Mestel, L., Spruit, H.C., 1987. MNRAS 226, 57.
Morin, J., Donati, J., Petit, P., Delfosse, X., Forveille, T., Jardine, M.M., 2010. MNRAS 407, 2269.
Pratt, Gabriel W., Hassall, B.J.M., Naylor, T., Wood, Janet H., 1999. MNRAS 307, 413.
Qian, S.-B., Liu, L., Zhu, L.-Y., Dai, Z.-B., Fernandez Lajus, E., Baume, G.L., 2012. MNRAS 422, L24.
Rappaport, S., Verbunt, F., Joss, P.C., 1983. ApJ 275, 713.
Reiners, A., Basri, G., 2008. ApJ 684, 1390.
Reiners, A., Basri, G., 2009. A&A 496, 787.
Reiners, A., Basri, G., 2010. ApJ 710, 924.
Ritter, H., 1980. A&A 85, 362.
Schoembs, R., 1987. A&A 181, 50.
Schoembs, R., Hartmann, K., 1983. A&A 128, 37.
Sherrington, M.R., Jameson, R.F., 1982. MNRAS 200, 861.
Stern, R.A., Schmitt, J.H.M.M., Pye, J.P., Hodgkin, S.T., Stauffer, J.R., Simon, T., 1994. ApJ 427, 808.
Verbunt, F., Zwaan, C., 1981. A&A 100, L7.
Vogt, N., Schoembs, R., Krzeminski, W., Pedersen, H., 1981. A&A 94, 29.
Wood, J.H., Horne, K., Berriman, G., Wade, R.A., 1989. ApJ 341, 974.