Acta Polytechnica CTU Proceedings **2**(1): 183–187, 2015 doi: 10.14311/APP.2015.02.0183

Close-In Substellar Companions and the Formation of sdB-Type Close Binary Stars

L. Y. Zhu[1,2,3], S. B. Qian[1,2,3], E.-G. Zhao[1,2], E. Fernández Lajús[4,5], Z.-T. Han[1,2,3]

[1] *Yunnan Observatories, Chinese Academy of Sciences, P.O. Box 110, 650011 Kunming, P.R. China*

[2] *Key Laboratory for the Structure and Evolution of Celestial Bodies, Chinese Academy of Sciences, P.O. Box 110, 650011 Kunming, P. R. China.*

[3] *Physical Sciences Department, Graduate University of the Chinese Academy of Sciences, Yuquan Road 19, Sijingshang Block, 100049 Beijing, China.*

[4] *Facultad de Ciencias Astronómicasy Geofísicas, Universidad Nacional de La Plata, 1900 La Plata, Buenos Aires, Argentina.*

[5] *Instituto de Astrofisica de La Plata (CCT La plata - CONICET/UNLP), Argentina.*

Corresponding author: zhuly@ynao.ac.cn

Abstract

The sdB-type close binaries are believed to have experienced a common-envelope phase and may evolve into cataclysmic binaries (CVs). About 10 % of all known sdB binaries are eclipsing binaries consisting of very hot subdwarf primaries and low-mass companions with short orbital periods. The eclipse profiles of these systems are very narrow and deep, which benefits the determination of high precise eclipsing times and makes the detection of small and close-in tertiary bodies possible. Since 2006 we have monitored some sdB-type eclipsing binaries to search for the close-in substellar companions by analyzing the light travel time effect. Here some progresses of the program are reviewed and the formation of sdB-type binary is discussed.

Keywords: hot subdwarf binary - photometry - individual: NY Vir, HS 0705+6700, NSVS 07826147.

1 Introduction

Hot subdwarf stars (sdB) lie in the extreme horizontal branch (EHB). They are burning helium in their cores and have very thin hydrogen envelopes. After leaving the main sequence, the progenitors of sdBs would evolve to red giant, ignite helium and settle down on the EHB (Heber 2009). They have high temperatures and gravities. To explain these characters, their progenitors must have experienced enhanced mass loss at the tip of red giant branch (Castellani and Castellani, 1993; D'Cruz et al., 1996). However, what causes this extreme mass loss remains an open question. Many authors suggested that the mass loss is triggered by the presence of a companion. In 2007, Silvotti et al., found a giant planet orbiting around a sdB star, V391 Pegasi, at a distance of 1.7 AU. After that, an even more extreme case was published by Charpinet et al., (2011). They reported the presence of two nearly Earth-sized bodies orbiting the sdB star KIC 05807616 at distances of 0.0060 AU and 0.0076 AU, with orbital periods of 5.7625 and 8.2293 hours, respectively. These detections support the way to form single sdB stars that these bodies were originally giant planets immersed in the red-giant envelope and massive enough to survive engulfment and triggered the enhanced mass loss necessary for the formation of an sdB star. So the close-in substellar companions paly an important role to form single sdB stars.

Actually, about half (or may be more) of the sdBs reside in close binaries (Morales-Rueda et al., 2006). Are there any substellar objects around sdB close binaries just like the substellars founded around the single sdB stars? Recently, some circumbinary substellars orbiting around sdB eclipsing binaries were indeed detected, such as HW Vir (Lee et al., 2009), HS 0705+6700 (Qian et al, 2009), NY Vir (Qian et al., 2012) and SDSSJ0820+0008 (Geier et al, 2012). The sdB close binaries are believed to be formed from binary systems through common envelope(CE) ejection (Han et al., 2002, 2003). Because the separation of the two components in sdB close binaries is much less than the size of the subdwarf progenitor in its red-giant phase, these systems must have experienced a CE phase. After spiral in and envelope ejection, the present binary system consisting of a sdB star and a low-mass companion star was formed with short periods. The presence of substellar tertiary, especially the close-in objects, orbiting sdB close binaries provides some clues to the interactive effect between them, and may give evidences of the formation of the planets and the sdB close binaries.

2 Targets and Method

For searching for close-in substellar companions of the sdB close binaries, we chose eclipsing sdB close binaries (i.e. HW Vir binaries) as our targets to monitor because their eclipsing profiles provide us with very useful information about their orbital period variations, which may be caused by the presence of third bodies. HW Vir binaries have been known for more than four decades. They are detached eclipsing binaries composed of a sdB star and a low-mass companion star. Till now, not more than fifteen of such objects were discovered. Their well-detached configuration indicates that their eclipses might not be influenced by the accretion-driven radiations from other parts (e.g., the accretion discs and hot spots etc.) observed in CVs. And the compact structures of both components make the eclipses in the light curves very narrow and deep. These characteristics favour a highly precise determination of their times of light minimum, generally with errors less than 0.0001days. Thus very small amplitude orbital period variations due to the substellar tertiaries can be detected by analyzing the observed-calculated (O-C) diagrams. Therefore they are the most hopeful targets for detecting substellar objects around them with light time effect. Using 2.4-m, 1-m and 60-cm telescopes in Yunnan Observatories, 2.16-m and 85-cm telescopes in Xinglong station of National Observatories and 2.15-m Jorge Sahade telescope in Argentina, we began to monitor HW Vir binaries since 2006. Our targets are listed in Table 1.

Table 1: Summary of our targets

Name	Coordinate (J2000)	Period h	Mag. (mag)
HW Vir	12 44 20.24 -08 40 16.8	2.801	V=11.2
NY Vir	13 38 48.14 -02 01 49.2	2.426	V=14.2
HS 0705+6700	07 10 42.09 +66 55 44.0	2.296	B=14.1
HS 2231+2441	22 34 20.89 +24 57 00.4	2.654	V=14.1
NSVS 14256825	20 20 00.51 +04 37 55.6	2.649	V=14.3
BULSC 16-335	14 45 20.21 -06 44 03.2	3.001	V=16.3
NSVS 07826147	15 33 49.40 +37 59 28.6	3.883	V=13.6
SDSSJ 0820+0008	08 20 53.5 +00 08 53.4	2.304	g=14.9
2M 1938+4603	19 38 32.61 +46 03 59.1	3.024	g=11.9
EC 10246-2707	10 26 56.47 -27 22 57.1	2.844	B=14.2
ASAS 102322-3737	10 23 21.89 -37 36 59.9	3.343	V=11.6

Supposing that there is a third body existing in this system, under the mutual gravitation force, the components of eclipsing pair would rotate around the barycenter of this triple system. Seen by a distant observer, the light-travel time of this system will change because of the change in the orbital movement caused by the additional body, which can result in the observed cyclic change in the O-C diagram constructed by the eclipsing timings. This light time effect is very useful to detect tertiaries within AU distance level in evolved eclipsing binaries compared with the radial velocity and transit methods, which have been extensively used to search for planets around solar-type main-sequence stars. That is because the high surface gravity of the evolved stars prevents us to achieve the high radial velocity precision required to detect planets, and the small size of the components (for example, $R_1 = 0.166$ and $R_2 = 0.152$ for NSVS 07826147 derived by For et al., 2010.) make the low probability of transits, see Silvotti (2009) for more information.

3 New Results

Here we present new results of our three targets (HS 0705+6700, NY Vir and NSVS 07826147) from our ongoing search for circumbinary substellars orbiting around sdB eclipsing binaries. For HS 0705+6700 and NY Vir, new observations confirmed our previous study (Qian et al., 2009, 2012). For NSVS 07826147, preliminary analysis of the O-C diagram constructed by our five years data implied the presence of a close-in planet orbiting around it at a distance about 0.64AU.

3.1 HS 0705+6700

HS0705+6700 (= GSC 4123-265) was listed as a dwarf candidate from the Hamburg Schmidt survey (Hagen et al. 1995). The observations indicated that it is an eclipsing binary. A detailed photometric and spectroscopic investigation was carried out by Drechsel et al. (2001). Absolute parameters of both components were determined suggesting that the primary is an sdB star, while the secondary is a cool stellar object.

A cyclic change in the O-C curve of HS 0705+6700 was discovered by Qian et al. (2009), which indicated the presence of a possible brown dwarf companion. It was later confirmed by Camurdan et al. (2012), Beuermann et al. (2012), and Qian et al. (2013) who revised the parameters of the brown dwarf. The $(O-C)_1$ diagram of the sdB-type binary HS 0705+6700 with respect to the following linear ephemeris,

$$Min.I = BJD\,2451822.760549 + 0.09564665 \times E, \quad (1)$$

was displayed in Fig. 1, where dots refer to our new data obtained after Qian et al. (2009). It is shown that, apart from the cyclic change reported by previous authors, there is an upward parabolic variation in the $(O-C)_1$ curve. This reveals a period increase at a rate of $\dot{P} = +9.8 \times 10^{-9}$ days/year. The angular momentum loss via gravitational radiation or/and magnetic braking should cause a decrease in the orbital period rather than increase. Moreover, the period increase cannot be

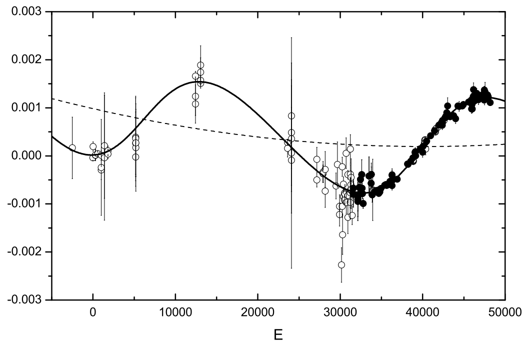

Figure 1: O-C diagram of HS 0705+6700. Dots refer to our new data obtained after Qian et al. (2009), and open circles to the other data. Dashed line refers to the continuous increase in the period, while the solid line to a combination of the period increase and a cyclic change.

explained by mass transfer between the components because of the detached configuration of the system. Therefore, the observed upward parabolic variation may be only a part of another cyclic change with very long-period that is caused by the light-travel time effect due to the presence of another substellar object in a wider orbit.

3.2 NY Vir

NY Vir (PG 1336-018) was discovered as a HW Vir binary by Kilkenny et al., (1998) which is composed of

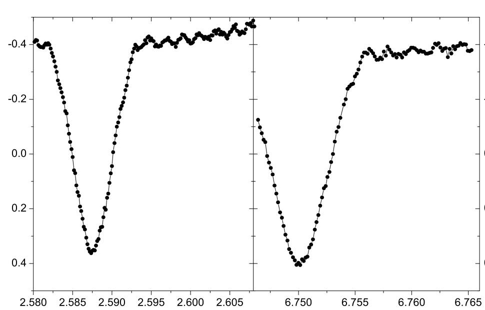

Figure 2: Eclipse profiles of NY Vir observed in November 2012 and April 2013 with the 2.15-m "Jorge Sahade" telescope. Dots represent the magnitude differences between the NY Vir and the comparison star.

a rapid pulsator and an M_5-type star. Kilkenny et al., (2011) found the orbital period of the binary is decreasing at a rate of $\dot{P} = -11.2 \times 10^{-13}$ d per orbit. A cyclic change was discovered to be superimposed on the long-term decrease by Qian et al. (2012), which was explained by the presence of a circumbinary planet. Qian et al. (2012) pointed out that the long-term period decrease can not be explained by angular momentum loss via gravitational radiation or/and magnetic braking and proposed that there is another substellar object in a wider orbit as in the case of HS 0705+6700. New observations of the sdB binary were obtained. The eclipse profiles obtained by using the 2.15-m "Jorge Sahade" telescope in Argentina were shown in Fig. 2. The new determined eclipse times confirm the presence of the circumbinary planet and the parameters will be revised by including more times of light minimum.

3.3 NSVS 07826147

NSVS07826147 (2M 1533+3759) has been suspected as a possible eclipsing sdB binary system by Kelley and Shaw (2007) using the data from the Northern Sky Variability survey and the Two Micron All Sky Survey. They derived the period of this system as 0.16177 days. Zhu and Qian (2009) improved its period as 0.16177046 days based on all available times of light minimum until that time. The detailed absolute parameters derived by the combination of photometric and spectroscopic observations were published by For et al., (2010). Till now, we have monitored this target for more than 5 years. New light curves obtained with the 85-cm telescope and the 2.4m telescope are displayed in Fig. 3. The constructed O-C diagram shows the trend of the periodic variation, which implies the presence of a close-in circumbinary planet in NSVS 07826147 at a distance about 0.64AU. The detailed analysis is in progress.

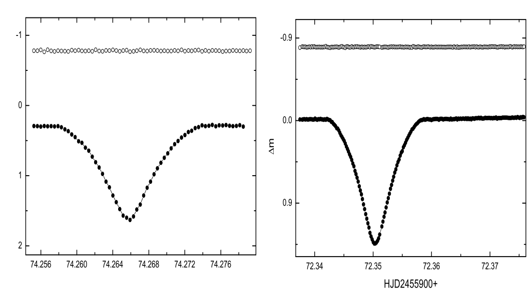

Figure 3: Light curves of NSVS07826147. Left panel: Eclipsing profiles of NSVS07826147 obtained with 85-cm telescope on May 26, 2012 in R band. Right panel: Obtained with 2.4-m telescope on Feb. 14, 2012 without filters. Dots refer to the magnitude differences between the target and the comparison star, and open circles to the magnitude differences between the comparison and check star.

4 Summary

One formation method of sdB-type binaries in theory is through a common envelope (CE) phase after the more massive star in the initially detached system evolves into a red giant. The ejection of the CE results in a large amount of angular momentum loss, and then a short-period sdB-type binary is formed. In previous section, new results of the three sdB-type eclipsing binaries are introduced. The presence of substellar companions especially the one orbiting NSVS 07826147 with the closest distance will give some constrains on the formation of this type of objects as well as on the interaction between red giants and their companions. To improve the results, more observations are required in the future.

Acknowledgement

This work is supported by Chinese Natural Science Foundation (No.11133007 and 11325315) and Yunnan Natural Science Foundation (No. 2013FB084). New CCD photometric observations were obtained with the 2.16m and 85-cm telescope at Xinglong station, the 2.4-m, 1.0-m, and 60-cm telescopes at Yunnan observatories in China, and the 2.15-m "Jorge Sahade" telescope in Argentina.

References

[1] Beuermann, K., Breitenstein, P., Debski, B., Diese, J., Dubovsky, P. A., Dreizler, S., et al., 2012, A&A 540, 8

[2] Castellani, M., Castellani, V., 1993, ApJ, 407, 649

[3] Camurdan, C. M., Zengin Camurdan, D., Ibanoğlu, C., 2012, NewA 17, 325 doi:10.1016/j.newast.2011.08.004

[4] Charpinet, S., Fontaine, G., Brassard, P., et al., 2011, Natur, 480, 496 doi:10.1038/nature10631

[5] D'Cruz, N. L., Dorman, B., Rood, Robert, T., O'Connell, R. W., 1996, ApJ, 466, 359 doi:10.1086/177515

[6] Drechsel, H., Heber, U., Napiwotzki, R., Ostensen, R., Solheim, J.-E., Johannessen, F., Schuh, S. L., Deetjen, J., Zola, S., 2001, A&A 379, 893

[7] For, B. Q., et al., 2010, ApJ, 708, 253 doi:10.1088/0004-637X/708/1/253

[8] Hagen, H-J., Groote, D., Engels, D., & Reimers, D. 1995, A&AS, 111, 195

[9] Han, Z. et al., 2002, MNRAS, 336, 449

[10] Han, Z. et al., 2003, MNRAS, 341, 669 doi:10.1046/j.1365-8711.2003.06451.x

[11] Heber, U., 2009, ARA&A, 47, 211 doi:10.1146/annurev-astro-082708-101836

[12] Kelley, N., Shaw, J. S., 2007, J. Southeast. Assoc. Res. Astron. 1, 13

[13] Kilkenny, D., 2011, MNRAS 412, 487 doi:10.1111/j.1365-2966.2010.17919.x

[14] Kilkenny, D., O'Donoghue, D., Koen, C., Lynas-Gray, A. E., van Wyk, F., 1998, MNRAS 296, 329 doi:10.1046/j.1365-8711.1998.01432.x

[15] Lee,J. W., Kim,S.-L., Kim,C.-H., et al. 2009,AJ, 137, 3181

[16] Geier, S., Classen, L., Brnner, P., et al., 2012, ASP Conference Series Vol. 452, 153

[17] Morales-Rueda, L., et al., 2006, Baltic Astronomy, 15, 187

[18] Qian, S.-B., Dai, Z.-B., Liao, W.-P., Zhu, L.-Y., Liu, L., Zhao, E. G., 2009, ApJ 706, L96

[19] Qian, S.-B., Zhu, L.-Y., Dai, Z.-B., Fernández Lajús, E., Xiang, F.-Y., and He, J.-J., 2012, ApJ 745, L23

[20] Qian, S.-B., Shi, G., Zola, S., 2013, MNRAS, in print

[21] Silvotti, R., 2009, International Journal of Astrobiology 8, 241

[22] Silvotti, R., Schuh, S., Janulis, R. et al., 2007, Natur, 449, 189

[23] Zhu, L. Y., Qian, S. B., 2010, Ap&SS, 329, 107

DISCUSSION

RAYMUNDO BAPTISTA: Light time travel effect is not the only interpretation for physical period changes in binary stars. An alternative is the magnetic activity cycle of the late-type star modulating the binary period. It is hard to believe a planet at 1 AU orbit would survive commom envelope phase of a binary which was at comparable separation before.

LIYING ZHU: Firstly, the cyclic period change caused by light time effect is strictly periodic change in O-C diagram not only quasi-periodic variation aroused by the magnetic activity cycle. Secondly, in our five-years monitor, no asymmetric light curves caused by the magnetic activity for these HW Vir binaries were found. Their light curves are very stable. Thirdly, One of our target SDSS J0820+0008 is composed of an sdB star and a brown dwarf, the cyclic change can not be explained by magnetic activity cycles. The detected planet at 1 AU orbit may be protected by the engulfment of the low mass stellar companion during the CE phase. And the other possibility is that the planet is the second-generation one.