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CIRCUMBINARY PLANETS ORBITING AROUND POST COMMON ENVELOPE BINARIES

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ABSTRACT

Most of the stars in the Galaxy are in binary systems. Binaries should be possible as the hosting stars of planets. Searching for planetary companions to binaries, especially evolved close binary stars, can provide insight into the formation and the ultimate fate of circumbinary planets and shed light on the late evolution of binary stars. In order to do this, we have chosen some post common envelope binaries including sdB-type eclipsing binaries and detached WD+dM eclipsing binaries as our targets and monitored them for several years. In this paper, we will present some of our new observations and results for three targets, NSVS 07826147, NSVS14256825 and RR Cae.

Key words: binaries:close - binaries: eclipsing - planetary system

1. INTRODUCTION

Since the first two extrasolar planets were discovered orbiting around the millisecond pulsar PSR 1257+12 in 1992 by Wolszczan & Frail (1992), it was confirmed that there are planets outside of our solar system. Three years later, the first Jupiter-mass companion to a solar-type star was discovered by Mayor & Queloz. (1995). After that, extrasolar planet hunting has become a hot field in astronomy. To date, nearly 2000 extrasolar planets have been detected according to the Extrasolar Planets Encyclopaedia (http://exoplanet.eu/). Most of them were detected around single stars, while a small fraction of them are around binaries or multiples. As we know, more than half of all stars are in binaries or multiple systems. Therefore it is expected that planet formation should be a common phenomenon in and around binaries. There have been two types of planetary orbits in binary star systems discovered. One is S-type, which refers to the planetary system with the planet orbiting around one of the two stars; the other is P-type, which refers to planetary systems with the planet orbiting around the entire binaries, i.e. a circumbinary planet.

In the present paper, we will focus on circumbinary planets orbiting around the evolved stars, especially sdB-type eclipsing binaries and detached WD+dM eclipsing binaries. These two groups belong to post common envelope binaries, which are believed to be formed from initially long-period detached binaries (Heber, 2009; Zorotovic & Schreiber, 1997). After the more massive component has evolved into a red giant, dynamical mass transfer occurs and the secondary ultimately overfills its own Roche lobe. Because the secondary cannot accrete all the transferred matter, a common envelope surrounding both stars will be formed. Due to the friction with the envelope, the two components spiral towards each other until enough orbital energy has been released to eject the envelope, so that a much closer binary consisting of the core of the giant (e.g. sdB, WD etc.) and a main sequence companion is formed. Searching for planets around them will give some constraints on the late stages of stellar evolution, and provide us with more knowledge on the formation and evolution of planets, especially on the ultimate fate of planets.

2. TARGETS AND METHOD

In order to search for circumbinary planets around evolved binary stars, we employ the timing method.

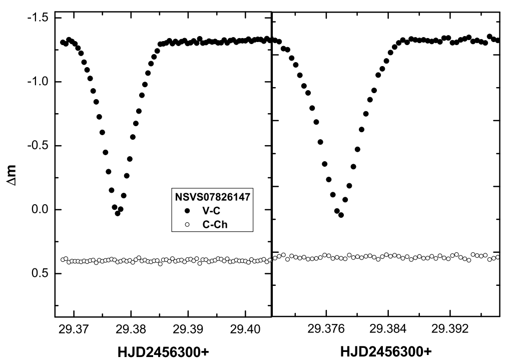

Figure 1. Left panel: Eclipsing profiles of NSVS 07826147 obtained with the 85-cm telescope at Xinglong Station on Feb. 5, 2013 in R band. Right panel: same as the left panel but in I band. Dots refer to the magnitude differences between the target and the comparison star, and open circles to the magnitude differences between the comparison and check star.

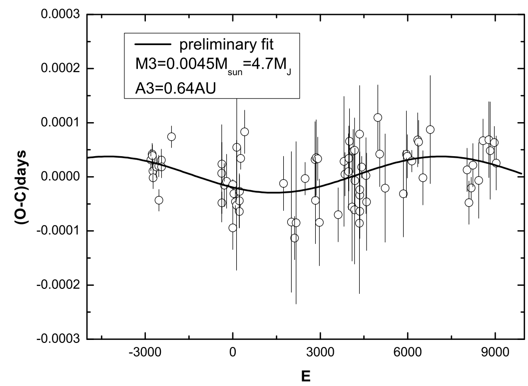

Figure 2. O-C diagram of NSVS 07826147. The open circles refer to high precision CCD observations. The solid line shows the preliminary fit, which indicates that there is a periodic variation.

Although the radial velocity and transit methods have been extensively used to search for extroplanets, the timing method has most successfully been applied to detect extrasolar planets around stars evolved beyond the first red giant branch. The timing method is based on the light time effect, which is the same method used in discovering the first extroplanets. Supposing that there is a third body existing in the system; under 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 an observed cyclic change in the observed-calculated (O-C) diagram constructed from eclipsing timings.

The targets we have chosen include two groups, sdB-type eclipsing binaries and the detached WD+dM eclipsing binaries. An sdB-type eclipsing binary is composed of a very hot subdwarf B type primary star and a very cool fully convective M-type secondary. The hot subdwarf stars (sdB) lie in the extreme horizontal branch (EHB). They are burning helium in their cores and have very thin hydrogen envelopes. A detached WD+dM eclipsing binary consists of a white dwarf primary and a main sequence M type secondary. Both groups are believed to have evolved through the common envelope ejection and will evolve into cataclysmic variables. They are well detached systems, which indicates that the eclipses will not be influenced by the accretion-driven radiations from the other parts, such as the accretion discs and hot spots observed in CVs. Both components of the targets are also compact objects, which makes the eclipse profiles in the light curves very deep. These characteristics favour a highly precise determination of the times of light minima, generally with errors less than 0.0001 days. Thus, very small amplitude orbital period variations due to the low mass tertiaries can be detected by analyzing the O-C diagrams. Therefore they are the most promising targets for detecting planets with the light tjeime 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, 2.4-m telescope in Thailand and 2.15-m Jorge Sahade telescope in Argentina, we have monitored these targets for several years.

3. OUR NEW RESULTS

A group of extroplanets and brown dwarfs have been discovered orbiting around sdB-type eclipsing binaries and detached WD+dM eclipsing binaries by our group and other investigators in the recent years, including HW Vir (Qian et al., 2008; Lee et al., 2009; Beuermann et al., 2012), NY Vir (Qian et al., 2012a; Lee et al., 2014), HS 0705+6700 (Qian et al., 2009; Beuermann et al., 2012; Qian et al., 2013), QS Vir (Qian et al., 2010a; Horner et al., 2007) and RR Cae (Qian et al., 2012b). Here we present new results for three targets, NSVS 07826147, HS 14256825 and RR Cae, from our ongoing project searching for circumbinary planets around post common envelope binary stars.

3.1. NSVS 07826147

NSVS07826147 (2M 1533+3759) was discovered as an eclipsing sdB binary system by Kelley & Shaw (2007) using data from the Northern Sky Variability survey and the Two Micron All Sky Survey. They derived a period for this system of 0.16177 days. Zhu & Qian (2010) improved the period to 0.16177046 days based on all available times of light minima available at that time. The detailed absolute parameters derived by the combination of photometric and spectroscopic observations were published by For et al. (2010). To date, 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. 1. With all the high precise times of light minima, the O-C diagram has been constructed, shown in Fig. 2. The O-C curve shows the

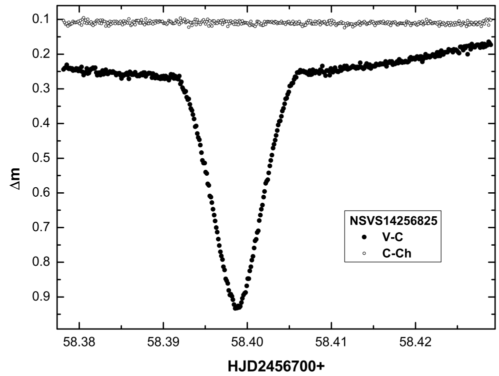

Figure 3. Eclipsing profiles of NSVS 14256825 obtained with the 2.4-m telescope of Yunnan Observatories on April 10, 2014 in R band. Symbols are the same as in Fig. 1.

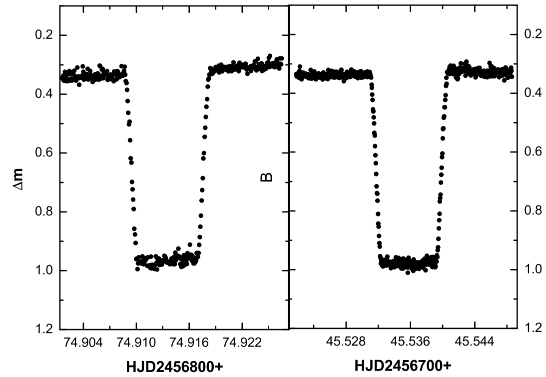

Figure 4. Two white-light eclipse profiles of the WD+dM eclipsing binary RR Cae observed in 2014 March and August with the 2.15-m telescope in Argentina. Symbols are the same as in Fig. 1.

trend of the small amplitude periodic variations. Preliminary analysis indicates that there may exist an additional body orbiting around NSVS07826147. The minimal mass of this third body is 4.7 Jupiter masswa and the corresponding maximal orbital radius is 0.64 AU. The preliminary fit is plotted with solid line in Fig. 2.

3.2. NSVS 14256825

NSVS 14256825 (=2MASS J20200045+0437564) was identified as an eclipsing sdB binary by Wils et al. (2007). After that many investigators including Qian et al. (2010b), Zhu et al. (2011), Kilkenny & Koen (2012), Beuermann et al. (2012), Almeida et al. (2013) and Lohr et al. (2014) have studied its period variation and claimed the period changes for this system. We have monitored NSVS14256825 photometrically since 2006. One of the eclipsing profile of this system obtained with 2.4m telescope in Yunnan Observatories is displayed in Fig. 3. Our O-C curve covers more cycles, especially the early cycles and shows the trend of obvious periodic variation with small amplitude (Zhu et al., 2011), which implies the existence of planets. A detailed analysis is in progress.

3.3. RR Cae

RR Cae was discovered to be an eclipsing binary by Krzeminski (1984). The cool white dwarf component is eclipsed by an M-type dwarf companion every 7.3 hours. A detailed photometric and spectroscopic investigation was recently presented by Maxted et al. (2007). They showed that RR Cae is a detached binary containing a cool white dwarf primary with a mass of $0.44\,M_\odot$ and an M4-type secondary with a mass of $0.182\,M_\odot$. We have studied the O-C diagram of this system and found thet there is a cyclic change undergoing an upward parabolic variation in this diagram (Qian et al., 2012b). The cyclic variation indicates that there is a circumbinary giant planet when its orbital inclination is larger than 17°.6. The orbital separation of the planet from the central pair is about 5.3 AU. The period increase cannot be explained by mass transfer between both components because of its detached configuration; and it is also opposite to the changes caused by angular momentum loss via magnetic braking or/and gravitational radiation. So the observed upward parabolic change is only a part of a long-period cyclic variation, which may suggest the presence of another giant circumbinary planet in a wide orbit. After this publication, we continued monitoring this target and obtained several new times of mid-eclipse. Two of the eclipsing profiles are plotted in Fig. 4. Our new timings confirm our previous results and the detailed parameters will be improved later.

4. SUMMARY

According to recent studies, more and more post common envelope binaries have been discovered to be host stars of planets. Here we present new observations of two eclipsing sdB binary systems, NSVS 07826147 and NSVS 14256825, and one detached WD+dM eclipsing binary, RR Cae. Based on all available timing data, we have analyzed their O-C diagrams. The O-C curves of these three systems all show cyclic variations due to the light time effect arising from the gravitational influence of planetary companions. The presence of planetary companions, especially the one orbiting NSVS 07826147 with the closest distance, will give some constraints on the formation of this type of object as well as on the interaction between red giants and their companions. To improve the results, more observations are required in the future.

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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.

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