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MAGNETIC CVs AS A BRIGHT REPRESENTATIVE OF CLOSE BINARIES

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ABSTRACT

Due to the lack of an accretion disk in a polar (magnetic cataclysmic variable, MCV), the material transferred from the secondary is directly accreted onto the white dwarf, forming an accretion stream and a hot spot on the white-dwarf component. During the eclipses, different light components can be isolated. Therefore, the monitoring of eclipsing polars could provide valuable information on several modern astrophysical problems, e.g., CVs as planetary hosting stars, mass transfer and mass accretion in CVs, and the magnetic activity of the most rapidly rotating cool dwarfs. In the past five years, we have monitored about 10 eclipsing polars (e.g., DP Leo and HU Aqr) using several 2-m class telescopes and about 100 eclipse profiles were obtained. In this paper, we will introduce the progress of our research group at YNOs. The first direct evidence of variable mass transfer in a CV is obtained and we show that it is the dark-spot activity that causes the mass transfer in CVs. Magnetic activity cycles of the cool secondary were detected and we show that the variable mass transfer is not caused by magnetic activity cycles. These results will shed light on the structure and evolution of close binary stars (e.g., CVs and Algols).

Key words: binaries: Stars: binaries : close–Stars: binaries : eclipsing–Stars: evolution

1. INTRODUCTION

Cataclysmic variables (CVs) are semi-detached binaries that contain a white-dwarf primary and a low-mass (spectral types of K and M) secondary. The cool component star fills the critical Roche lobe and transfers mass to the white-dwarf component (e.g., Warner 1995). In a normal CV, the transferred materials form an accretion disk around the white dwarf. However, in a polar (magnetic CV), the magnetic field of the white dwarf is strong enough to prevent the formation of an accretion disk (e.g., Giovannelli & Sabau-Graziati 2012). The transferred materials from the secondary are quickly and directly accreted onto the white dwarf and form an accretion stream and a hot spot on the white dwarf. During the eclipses, light components from the accretion stream and the spot on the white dwarf can be isolated. At the same time, the eclipse times can be determined to a high precision. Therefore, eclipsing polars can provide invaluable information for several problems of modern astrophysics, e.g., CVs as planetary hosting stars, the character and physical mechanisms of mass transfer and mass accretion in CVs, and the magnetic activity of rapidly rotating dwarfs in CVs. In this paper, we will review these aspects in detail.

2. POLARS AS A PLANETARY HOSTING STAR

Ten eclipsing polars (e.g., DP Leo, V2301 Oph, EK UMa, HU Aqr, UZ For, and MN Hya) were selected and monitored photometrically from 2009 using the 1.0-m and 2.4-m telescopes at Yunnan observatories in China, the Danish 1.54-m telescope at La Silla, the 2.15-m "Jorge Sahade" telescope in Argentina, and the 2.4-m telescope in Thailand. The white-light eclipse profile of the eclipsing polar MN Hya observed on April 6, 2013 is shown in Fig. 1. This eclipse profile was obtained using the Danish 1.54-m telescope at La Silla. As shown in the

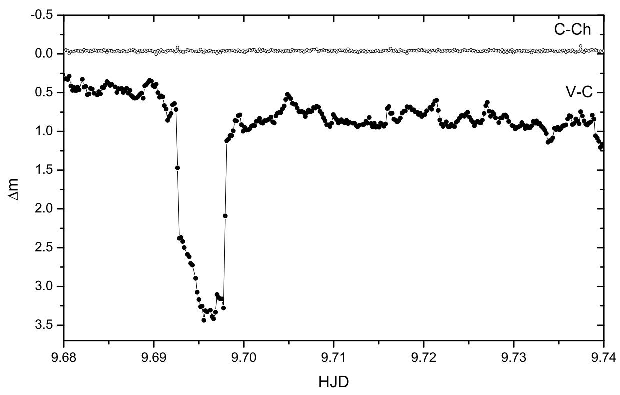

Figure 1. White-light CCD photometric light curve of MN Hya observed on April 6, 2013 using the using the Danish 1.54-m telescope at La Silla.

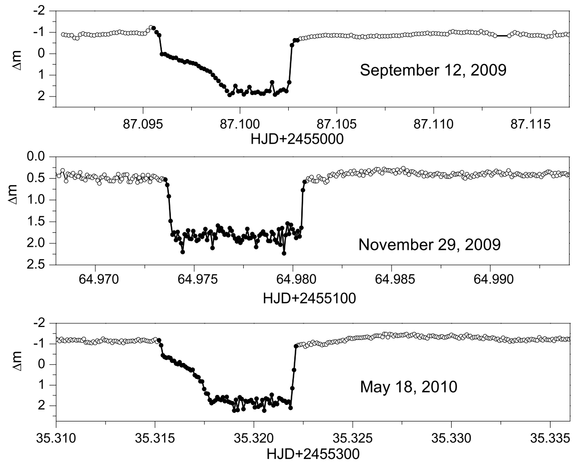

Figure 2. White-light eclipsing profiles of HU Aqr obtained by using the 2.4-m telescope in Yunnan observatories.

figure, the eclipse starts with the limb of the secondary star eclipsing the accretion hot spot, with the white dwarf being eclipsed at nearly the same time. Then, the accretion stream is the dominant source of brightness with a small contribution from the secondary, and finally only the red-dwarf component star is visible and provides a constant contribution. The sequence of the egress is approximately reversed.

Because the accretion stream and hot spot on the white dwarf can be isolated during the eclipses, the times of ingress and egress of eclipsing polars can be determined with a high precision. Very small-amplitude cyclic changes in the observed-calculated (O–C) diagram can be detected. Therefore, they are good targets to search for substellar objects orbiting CVs by analyzing the light travel time effect. Some substellar objects were recently discovered to be orbiting the polars (e.g., Qian et al. 2010a). Three eclipse profiles of HU Aqr are shown in Fig. 2. They were obtained in 2009 and 2010 using the 2.4-m telescope at the Yunnan observatories. As shown in the figure, the profiles of the ingress vary with time, while those of the egress are stable. The system was in a high brightness state on Sep. 12, 2009 and May 18, 2010 and we could see the accretion stream, while it was at a low brightness state on November 29, 2009. Since the profiles of the egress are stable, the times of mid-egress can reliably be used for period investigation. Qian et al. (2011) proposed two planetary objects orbiting the eclipsing polar. This object was then monitored using the 2.4-m and 1.0-m telescopes at Yunnan observatories in China, the 2.15-m Jorge Sahade telescope in Argentina, and the 2.4-m telescope in Thailand. New data will be used to confirm and used to revise the parameters of those planets. By using the same method, substellar objects orbiting other evolved binaries were discovered. Some examples detected by our group are those orbiting the detached white-dwarf binaries QS Vir and RR Cae (Qian et al. 2010b, 2012a) and the subdwarf B-type binary NY Vir (Qian et al. 2012b).

3. CHARACTER OF MASS TRANSFER AND MASS ACCRETION

Mass transfer is very important for understanding the evolution and observational properties of close binary stars. Most CVs (e.g., polars and some dwarf novae and nova-like CVs) show brightness changes in different states (e.g., high, intermediate, and low brightness states). The most plausible reason for these state changes is variation of mass transfer and mass accretion. However, direct evidence is lacking because of the influence of an accretion disk in a normal (non-magnetic) CV. Because they lack an accretion disk, the transferred material from the secondary in polars is quickly and directly accreted onto the white dwarf. Monitoring of eclipsing polars provides a good chance to study the properties of mass transfer in close binary stars. However, no eclipsing polars have been monitored for a long time, and only a few non-eclipsing polars have been monitored photometrically, including the brightest polar AM Her (e.g., Hessman et al. 2000; Kafka & Honeycutt 2003, 2005; Wu & Kiss 2008).

Three of the white-light eclipse profiles of HU Aqr obtained in 2011 using the 2.4-m telescope in Yunnan observatories are shown in Fig. 3. As shown in the figure, HU Aqr varied from a high state to a low state. On September 9, 2011 HU Aqr was at a high brightness state, and the distortion in the ingress profile is visible, suggesting that there is an accretion stream from the secondary to the white-dwarf component. At the same time, we could see a hot spot on the white dwarf. Therefore, the system is at the high brightness state. Both the existence of the accretion stream and of the hot spot reveal a high rate of mass accretion at high brightness state. From December 6 to 16, 2011, the system declined to a low brightness state, the distortion in the ingress profile disappeared and the eclipse profiles became symmetric. These suggest that there are no hot spots on the white dwarf and no accretion streams are seen between the components. These observational

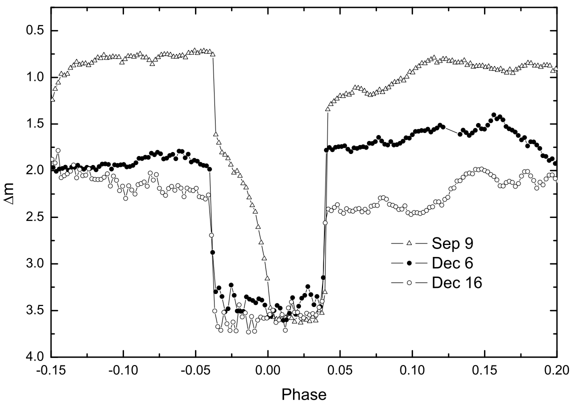

Figure 3. Comparison of eclipsing profiles in high and low brightness states.

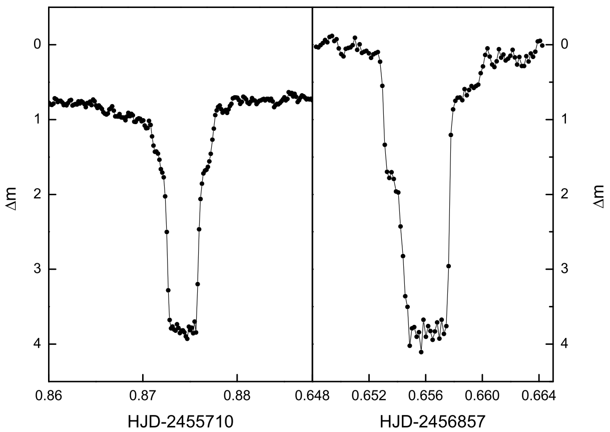

Figure 4. Eclipsing profiles of V2301 Oph obtained with the 2.15-m "Jorge Sahade" telescope in Argentina.

properties indicate that no mass transfer and accretion between both components occured during low brightness states. The out-of-eclipse brightness variation is correlated with the change of the eclipse profile suggesting that both the hot spot and the accretion stream are produced instantaneously. This is direct evidence of variable mass transfer and accretion in the CV.

4. MAGNETIC ACTIVITY OF THE RAPIDLY ROTATING DWARFS

Two eclipse profiles of the polar V2301 Oph observed on May 29, 2011 and on June 18, 2014 are shown in Fig. 1. The two profiles were observed using the 2.15-m Jorge Sahade telescope at Complejo Astronomico El Leoncito (CASLEO), San Juan, Argentina. During the observation, a Versarray 1300B camera with a thinned EEV CCD36-40 de 1340×1300 pix CCD chip was used, and no filters were used. At the bottoms of the eclipses, the white dwarf together with its hot spot and the accretion stream all are eclipsed by the cool secondary. Only the red-dwarf component is visible and provides a constant contribution. Therefore, it is the only chance to measure the brightness change of a mass donor in a CV caused by the activity of a dark spot. The secondary in a CV is usually a cool K- or M-type star that rotates about 300 times as the Sun does. By monitoring an eclipsing polar, we can understand the properties of dark-spot activity and magnetic activity cycles.

5. DISCUSSIONS AND CONCLUSIONS

Based on previous discussions we concluded that eclipsing polars are very useful for investigating several interesting questions in modern astrophysics. We have monitored this type of binary star for several years and some preliminary results have been obtained. We show that planets and brown dwarfs can exist in a completely different kind of host stars, i.e., polars. The observations in the previous section give direct evidence for variable mass transfer and accretion in CVs. A cyclic brightness variation of the secondary in HU Aqr was discovered that can be explained by the dark-spot activity cycle. It is the first time an activity cycle for a fast-rotating mass donor in a CV has been detected. Our results reveal that the variable mass accretion is not caused by magnetic activity cycles of the fast-rotating red dwarf. We will continue to monitor thos group of stars and details will be studied in the future.

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