Magnetic Activities in Outer Atmosphere of the RS CVn-type Binary SZ Psc

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Abstract. We present the results of time-resolved high-resolution spectroscopic observations of the very active RS CVn-type star SZ Psc, obtained during two consecutive observing nights in 2011 October. Chromospheric activity indicators (including the H_α, Na I D_1, D_2, He I D_3, and H_β lines) formed at different atmospheric heights were analyzed using the spectral subtraction technique, which show the remarkably different behavior and reveal a series of interesting magnetic activity phenomena during our observations. Blue-shifted absorption feature presented in the subtracted spectra, as a result of cool prominence motion while seen in projection against the stellar disk, was found in the first observing night. This event was associated with the subsequently strong optical flare observed in our second observing night. The flare was characterized by the prominent He I D_3 line emission, together with stronger chromospheric emission in other active lines. An obviously developmental absorption feature occurred on the blue wings of the Balmer line profiles, accompanied by the gradual decay of flare, which can be explained as cool post-flare loops.

1. Introduction

Magnetic activity phenomena usually manifested in solar physics were also widely observed in cool stars, which are very intense due to their deep convection zone coupled with high rotation rates resulting in an efficient magnetic dynamo. Rotational rate decreases with age because of the increasing moment of inertia and the losing angular momentum through magnetic braking during stellar evolution, so the magnetic activity level of cool stars indirectly depends on stellar age (Schrijver & Zwaan 2000). At Yunnan Observatories, we began a long-term high-resolution spectroscopic monitoring project for some late-type stars at different evolution stages from pre-main sequence stars to evolved stars, to study their magnetic activity (detecting optical flares, searching for prominence-like events, exploring the rotational modulation of chromospheric activity, and investigating the evolution of active regions) using the information derived through several optical chromospheric activity indicators formed at different atmospheric heights. In the present work, we focus on one of the most active RS CVn-type system SZ Psc.

SZ Psc is an eclipsing double-lined RS CVn system, consisting of F8V-IV hotter and K1IV cooler components, with an orbital period of about 3.97 days. The cooler component shows strong chromospheric activity, as demonstrated by strong chromospheric emission in the Ca II H & K, H_α and Ca II infrared triplet lines (Jakate et al. 1976; Bopp 1981; Ramsey & Nations 1981; Huenemoerder & Ramsey 1984; Fernàndez-Figueroa et al. 1986; Popper 1988; Frasca & Catalano 1994; Eaton & Henry 2007; Zhang & Gu 2008; Cao & Gu 2012). Here we present the preliminary result about a series of interesting magnetic activity phenomena occurred on SZ Psc, based on time-resolved high-resolution spectroscopic observations obtained during two consecutive observing nights.

2. Observations and data reduction

Spectroscopic observations of SZ Psc were made during two observing nights: October 24 and 25, 2011, using the direct echelle mode (DEM) of the Lijiang Exoplanet Tracker (LiJET) at 2.4 m telescope of the Lijiang station of the Yunnan Observatories, China. The echelle spectrograph has a resolving power of about 28000 and a 4096×4096 pixels CCD detector. The spectrum reduction was performed with the IRAF package following the standard procedures. In total, 51 spectra of SZ Psc were obtained during observations, and exposure times were typically 600s and sometimes 900s. The orbital phase was derived according to the revised ephemeris from Eaton & Henry (2007).

3. Spectral synthesis

We derived the chromospheric contribution in H_α, Na I D_1, D_2, He I D_3, and H_β lines using the spectral subtraction technique described in detail by Barden (1985) and Montes et al. (1995). In this method the synthesized spectrum was constructed from artificially rotationally broadened, radial velocity shifted, and weighted spectra of slowly rotating inactive stars with the similar spectral type and luminosity class as the two components of the binary system, which represents the contribution of the non-active state of the system. So, the subtraction between the observed and the synthesized spectra provides the pure chromospheric activity emission caused by magnetic activity.

For our situation, the synthesized spectra were constructed using the program STARMOD (Barden 1985). We used two inactive stars HR7560 (F8V) and HR7690 (K1IV) observed during the same observing run as the active system as reference stars in the synthesized spectral construction. Examples for spectral subtraction technique are shown

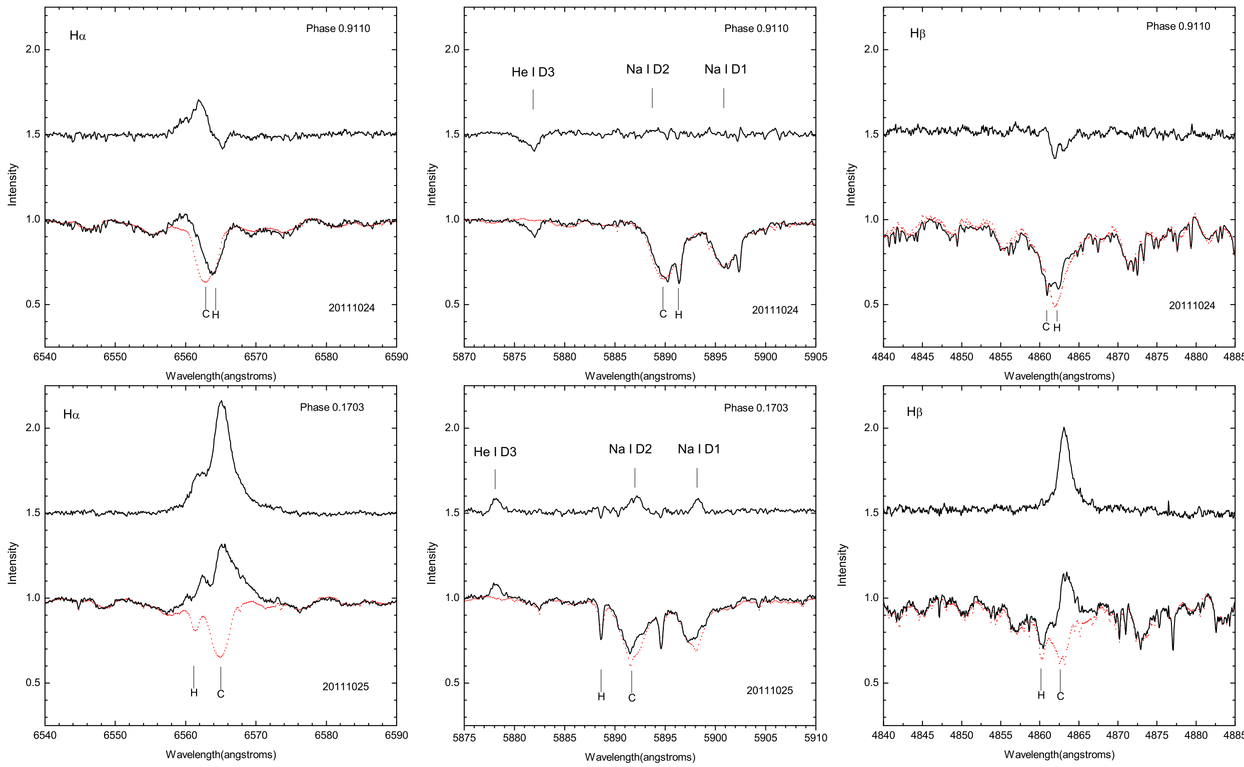

Figure .1: Examples of the observed, synthesized, and subtracted spectra for the H_α, He I D_3, Na I D_1, D_2, and H_β line spectral regions at orbital phases 0.9110 (the first observing night) and 0.1703 (the second observing night). For each panel, the lower solid-line is the observed spectrum, the dotted line represents the synthesized spectrum and the upper spectrum is the subtracted one shifted for better display. Also, "C" and "H" indicate the cooler and hotter components of the system, respectively.

in Figure .1.

4. Discussion

4.1 Prominence activity

After applying the spectral subtraction, it was found that the subtracted H_α line shows obviously chromospheric emission and there is an extra absorption feature in the red wing of emission profile during our first observing night, and the H_β line exhibits a super absorption. The He I D_3 line also shows a stronger absorption feature than the systhesized spectrum around this spectral region. As shown in Figure .2, all the subtracted H_α, H_β, and He I D_3 line profiles were corrected to the rest frame of the cooler component, and we found that the absorption features were blue-shifted relative to the cooler component of system, which could be explained by a prominence having upward motion while seen in projection against

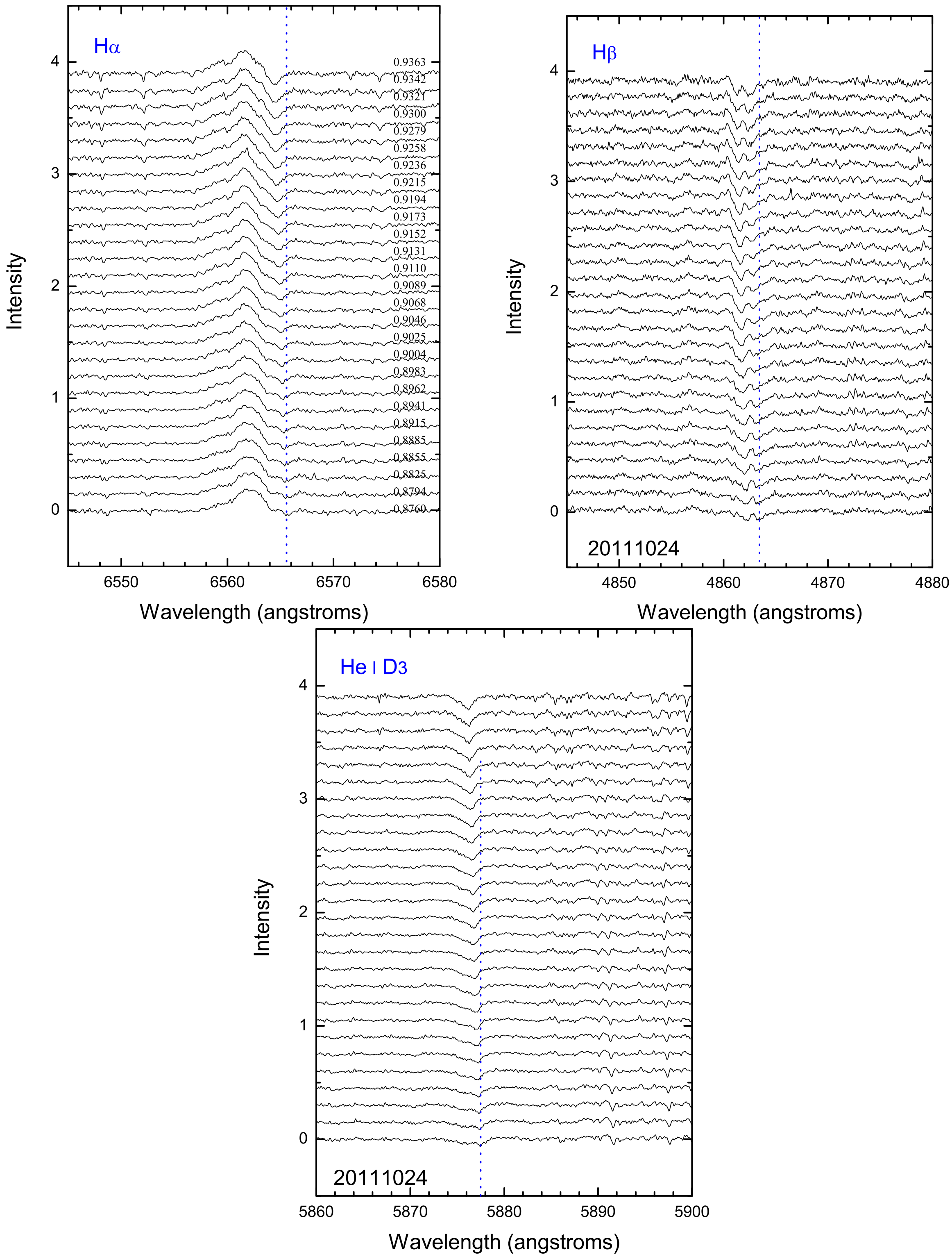

Figure .2: The subtracted H_α, H_β, and He I D_3 lines derived during the first observing night, are aligned on the cooler component's rest frame in phase order. The vertical lines (dotted lines) highlight the motion of absorption features.

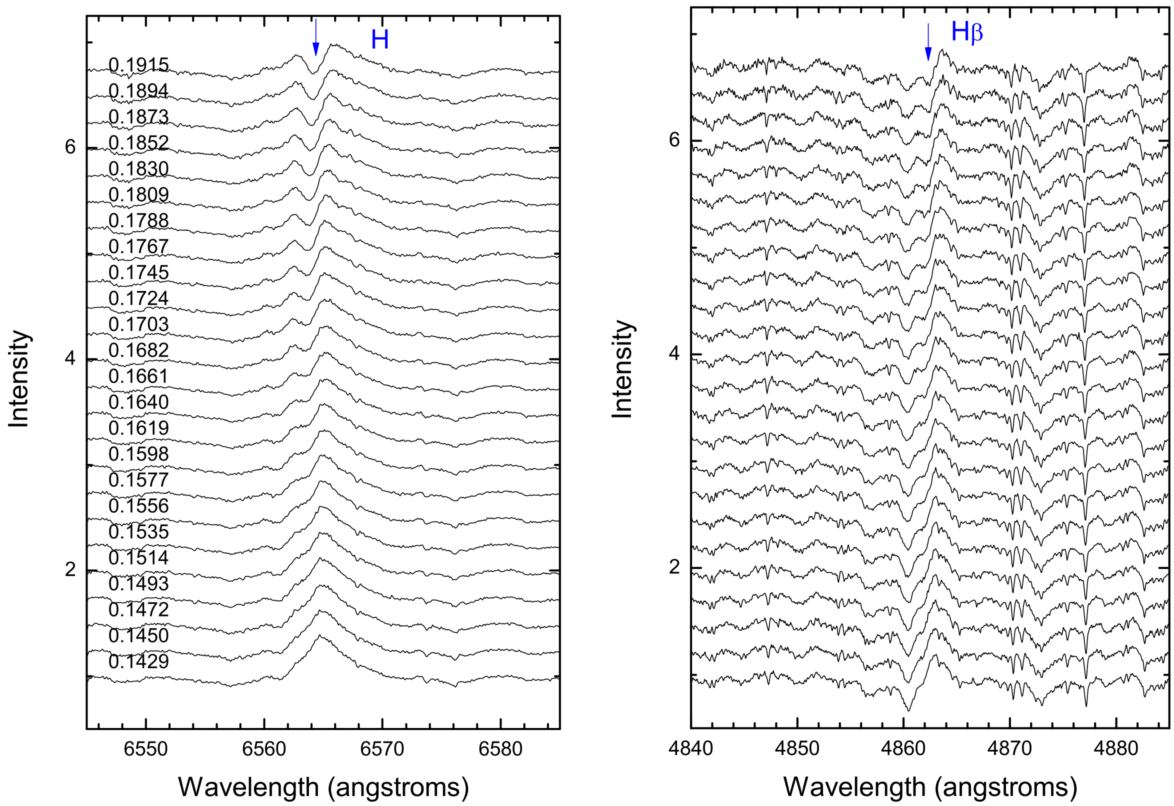

Figure .3: The H_α and H_β line profiles observed during the flare, and shifted arbitrarily.

the stellar disk.

4.2 Optical flare

From Figure .1, it can be found that the He I D_3 line shows emission at the night of October 25, which is the most important evidence in support of an optical flare event occurred in the case of SZ Psc. The simultaneously stronger emission of the H_α and H_β lines than the previous night is also associated with this flare event. The Na I D_1, D_2 lines show obvious filled-in by chromospheric emission from the cooler component during the flare. We did not capture the entire life-cycle of the flare from initial outburst to the end, because of limited observations and observational gap between our two observing nights. The flare shows a gradual decrease in emission according to the measured EWs of the chromospheric activity lines, which suggests that our observations were part of gradual decay phase of a flare.

Interestingly, a X-ray flare event was detected by MAXI/GSC on 2011 November 5 from 18:20 UT (MJD 55870.764) to 23:03 UT (MJD 55870.960) (Negoro et al. 2011), which occurred around the phase of primary eclipse which is between our two observing nights but three orbital cycles apart. So, both optical flare and X-ray flare erupted at a very similar and long-lived active region over the surface of SZ Psc.

4.3 Post-flare loops

Observed Balmer line profiles revealed extremely interesting feature during the flare (see Figure .3). A distinct absorption was seen on the blue wing of the emission profile and evolved with time as indicated by the arrow in the figure. The absorption feature can be explained by cool post-flare loops projected against the bright flare background, which sometimes occur during the gradual decay phase of large two-ribbon flares in solar case and can last for several hours (Wiik et al. 1996).

5. Conclusions

Based on time-resolved high-resolution spectroscopic observations obtained during two consecutively observing nights: October 24 and 25, 2011, a series of interesting magnetic activity phenomena were detected on SZ Psc in short period of time, including prominence activity, optical flare, and post-flare loops. A few hours interval between the prominence activity and subsequent optical flare, indicates that they probably occurred at the same region for a nearly four days periodic system. It can be concluded that this prominence event was associated with the optical flare, and the prominence activity triggered the flare eruption. Two-ribbon flares are closely related to the evolution of filament in solar case, and post-flare loops usually occur during the decay phase of flare. Therefore, this denotes a large two-ribbon flare was detected in the system of SZ Psc during our observations.

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The town of Flagstaff welcomed the meeting with open arms! Karaoke night at Granny's Closet was particularly popular.