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Chromospheric activity on late-type star LQ Hya

Liyun Zhang [a,b,*], Qingfeng Pi [a,b], Zhongzhong Zhu [a,b], Xiliang Zhang [b,c], Zhongmu Li [d]

[a] College of Science/Department of Physics & NAOC-GZU-Sponsored Center for Astronomy Research, Guizhou University, Guiyang 550025, PR China
[b] Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, Kunming 650011, PR China
[c] National Astronomical Observatories/Yunnan Observatory, Chinese Academy of Sciences, Kunming 650011, PR China
[d] Institute for Astronomy and History of Science and Technology, Dali University, Dali 671003, PR China

HIGHLIGHTS

- We present new high-resolution spectra of LQ Hya to discuss chromospheric activity.
- All chromospheric activity indicators of our spectra confirm chromospheric emission.
- It seems that there is a weak rotation modulation of chromospheric activity in our data.
- The contemporaneous chromospheric plage spatially associated with photospheric spots.

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ABSTRACT

We present new high-resolution echelle spectra of LQ Hya to study its chromospheric activity. We analyzed our spectroscopic observations including several optical indicators of chromospheric activity (the He I D_3, Na I D_1, D_2, H_α, and Ca II infrared triplet lines), by means of the spectral subtraction technique. All the chromospheric activity indicators (the Na I D_1, D_2, H_α, and Ca II IRT lines) confirmed chromospheric emissions. The ratio of EW_{8542}/EW_{8498} for LQ Hya is around 1.5, which indicates that there is optically thick emission in a plage-like region. As for the Ca II IRT and H_α lines, it seems that there is also a weak rotation modulation of chromospheric activity in our data, which might be explained by the strong plage or flare. The contemporaneous monitoring of photospheric and chromospheric emissions for LQ Hya indicate chromospheric plages might spatially associated with the spots.

1. Introduction

Late-type stars (spectral types F to L, and evolutionary stages from the pre-main sequence to giant) with thick convective zones and rapid rotation exhibit the phenomena of magnetic activity, such as starspot, plage, flare,... (Baliunas et al., 1995; Güdel, 2002, 2004; Berdyugina, 2005; Hall, 2008; Strassmeier, 2009; Lanza, 2010; etc). However, the details of the active phenomena are not well understood in many late-type stars (Zhang, 2011).

LQ Hya (K1 V) is a very active star with vsini = 25.6 km s^{-1} and a orbital period of $1^d.60$ (Fekel et al., 1986; Strassmeier et al., 1997; Donati, 1999). The activities are indicated by a photospheric starspot (Eggen, 1984; Jetsu, 1993; Strassmeier et al., 1993; Cutispoto et al., 2001; Alekseev and Kozlova, 2002), and a Doppler image (Rice and Strassmeier, 1998; Strassmeier et al., 1993), the chromospheric emission (Fekel et al., 1986; Strassmeier et al., 1990; Vilhu et al., 1991; Basri and Marcy, 1994; Montes et al., 1999, 2001; López-Santiago et al., 2010), transition region (Simon and Fekel, 1987), magnetic cycle (Strassmeier et al., 1997; Donati, 1999; Oláh et al., 2000; Berdyugina et al., 2002; Donati et al., 2003; Lehtinen et al., 2012), and even by occasional flares (Montes et al., 1999; Covino et al., 2001). The chromospheric activity of LQ Hya shows strong emissions in the Ca II H & K lines (Bidelman, 1985, Fekel et al., 1986; Strassmeier et al., 1990), emission above the continuum (even in the quiescence) of the H_α line (Frasca et al., 2008; etc), a filled-in absorption of the H_β line, and a strong filled-in absorption in the Ca II IRT lines (Montes et al., 2001).

In this paper, we present new high resolution spectroscopic observation of LQ Hya, which was analyzed using the spectral subtraction technique. Then, we discuss the Li I 6708 Å line, the behavior of chromospheric activity, and chromospheric properties.

2. New CCD spectroscopic observation of LQ Hya

Our new high-resolution spectroscopic observations were made on five days (Dec. 30–31, 2009, and Feb. 2–4, 2010) with a 2.16 m

* Corresponding author at: College of Science/Department of Physics & NAOC-GZU-Sponsored Center for Astronomy Research, Guizhou University, Guiyang 550025, PR China. Tel./fax: +86 851 362 7662.
E-mail address: liy_zhang@hotmail.com (L. Zhang).

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Table 1
The observational log of the object LQ Hya and template stars.

Name	Spectral	HJD (days)	Date	Exp time	The signal to noise of the spectra					
		24,+	day-month-year	n * second	Na I D1 D2	H alpha	Li 6708	Ca II 8498	Ca II 8542	Ca II 8662
LQ Hya	K1 V	55196.9377	30-12-2009	2 * 3600	79	110	112	103	116	108
LQ Hya	K1 V	55197.9401	31-12-2009	2 * 3600	61	84	85	78	86	80
LQ Hya	K1 V	55230.8128	2-2-2010	2 * 3600	74	102	104	95	104	98
LQ Hya	K1 V	55231.7745	3-2-2010	2 * 2400	68	100	104	99	111	103
LQ Hya	K1 V	55231.9496	3-2-2010	2 * 3600	91	126	131	118	130	120
LQ Hya	K1 V	55232.7825	4-2-2010	2 * 3600	77	107	110	99	110	101
HR 222	K2 V	55197.7007	31-12-2009	1 * 1500	99	136	144	131	146	134
HR 222	K2 V	55230.6019	2-2-2010	1 * 1500	82	113	117	104	115	108
HR 222	**K2 V**	**55232.6217**	**4-2-2010**	**1 * 1500**	**131**	**159**	**196**	**179**	**199**	**185**
HR 166	K0 V	55232.6012	4-2-2010	1 * 1500	128	173	181	158	174	161
HR 1614	K3 V	55196.8431	30-12-2009	1 * 1800	61	61	84	87	77	86

Note: The spectra of HR 222 on Feb. 4, 2010 (the bold one) was used as the template.

telescope of Xinglong station of the National Astronomical Observatories of China. A spectral resolution of the Coude echelle spectrograph is about 37,000 with a spectral red region of 560–910 nm (Zhao and Li, 2001). The reciprocal dispersions and corresponding spectral resolutions determined as the FWHM of arc comparison lines were described in the paper of Zhang and Gu (2008). We also observed several inactive stars (HR 222, HR 166, and HR 1614 with the spectral type and luminosity class similar to LQ Hya) to construct the synthesized spectra. Standard reduction of the spectra was performed using IRAF packages,[1] which involved zero subtraction, flat-fielding, cosmic-ray removal, background subtraction, and spectrum extraction. The wavelength calibration was obtained by using the spectra of a Th–Ar lamp. Our spectra were normalized by a low-order polynomial fit. The observing log of our object and several inactive stars is listed in Table 1. Since the signal to noise of the single spectra is low at some time because of the efficiency of our telescope and bad weather, we had to combine two adjacent spectra.

3. The chromospheric activity analysis

The Na I D_1, D_2, H_α and Ca II IRT lines are very useful diagnostic indicators of chromospheric activity for late-type stars (Montes et al., 1997, 2004; Zhang, 2011; etc.). Our normalized spectra of LQ Hya were analyzed by a spectral subtraction technique using the program STARMOD (Barden, 1985; Montes et al., 1995). During the program, the synthesized spectra were constructed from rotationally broadened, and radial-velocity shifted of the inactive star. In comparison, HR 222 is the best template of several stars for LQ Hya by the sum of squared residuals using the Starmod program. Therefore, we chose HR 222 as the template star to construct the synthesized spectrum. During the analysis, the vsini value of LQ Hya was determined from the spectra spanning the wavelength ranges 6389–6477 Å and 6615–6706 Å where they contained a lot of metallic spectra lines (Zhang and Gu, 2008). Using the starmod program, we determined the broadened rotational velocity of LQ Hya. This value (LQ Hya: 28 km s^{-1}) is close to the results derived by Donati (1999), Montes et al. (2001) and Frasca et al. (2008). All the observed, synthesized and subtracted spectra are displayed in Fig. 1, where the synthesized spectra are not the real spectra and they have been broadened from the template spectra. In our six spectra, the Na I D lines are characterized by deep absorption. The cores of the lines do not show any reversal. The application of the spectral subtraction technique reveals that the cores of the Na I D_1, D_2 lines exhibit weak excess emissions. All the Ca II IRT lines exhibit obvious self-reversal in the cores. The spectral subtraction reveals clear Ca II IRT excess emissions. All the H_α line exhibits obvious emission above the continuum in the line. The spectral subtraction of LQ Hya shows clear strong excess emissions. All these confirm the active behavior of LQ Hya (Montes et al., 1999; Alekseev and Kozlova, 2002; Frasca et al., 2008; López-Santiago et al., 2010; etc). It is well known that the He I D_3 line is a probe for detecting flare-like events (Zirin, 1988). We did not observe obvious emissions in the He I D_3 line, which means that there might be no strong flare-like episodes for LQ Hya during our observing seasons.

The equivalent widths (EWs) of the excess emissions were evaluated on the subtracted spectra by integrating them over the emission profile using the IRAF SPLOT task. The EWS and their errors were used in a method similar to the previous paper of Zhang and Gu (2008). The net EWs of the excess emissions are listed in Table 2, which include HJD, the phase, the net EWs of Na I D_1, D_2, H_α and Ca II IRT lines, Li I 6708 Å line, and the ratio of Ca II EW_{8542} and EW_{8498}. The phases were calculated using the ephemeris MinI = $HJD(Hel.)2448270.0 + 1^d.600656E$ (Frasca et al., 2008).

The ratio of excess emissions, EW_{8542}/EW_{8498}, is an indicator of the chromospheric structure (plage, prominence). The ratio of EW_{8542}/EW_{8498} for LQ Hya was around 1.5 (Table 2). These small ratios indicate that there are optically thick emissions in plage-like regions. These low values were also found in many late type stars by other authors, for example, Cao and Gu (2012), Lázaro and Arévalo (1997), Arévalo and Lázaro (1999), Montes et al. (2001), Gu et al. (2002), Gálvez et al. (2009) and Zhang and Gu (2008).

4. The Li I line

The Li I 6708 Å line is an important diagnostic of age because it is easily destroyed by thermonuclear reactions in the stellar interior. Because the Li I line is blended with the nearby Fe I 6707.41 Å ($vsini > 8$ km/s), the real equivalent width of the Li I was calculated by subtracting the EW of Fe I 6707.41 line (Montes et al., 2001), which could be obtained from the empirical relationship with color index (EW(6707.441 Å) = 20(B-V)-3 m Å) given by Soderblom et al. (1993). In our spectra, we obtained a mean value of 228 ± 5 m Å for the Li I (Table 2). Our result is similar to the 234 m Å reported by Fekel et al. (1986) and the 243 m Å by Montes et al. (2001). The value is closer to the upper envelop of the Pleiades cluster (Montes et al., 2001), which indicates that LQ Hya is a possible member of Pleiades.

5. Discussions and conclusions

Our data are very important to determine the chromospheric properties. Frasca et al. (2008) found that LQ Hya shows a clear rotational modulation of the H_α emission by analyzing the

[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

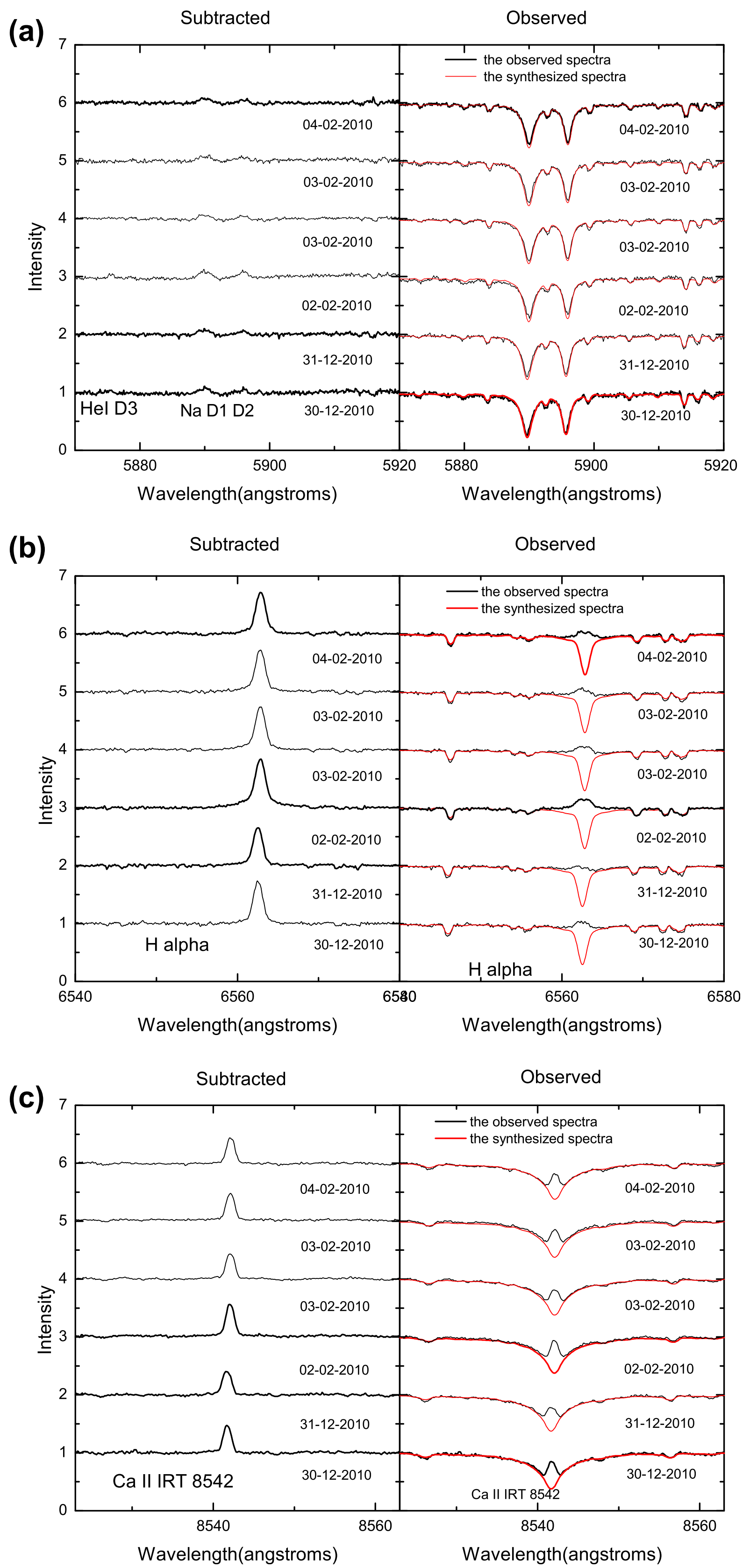

Fig. 1. All the observed, synthesized, and subtracted spectra of LQ Hya in the He I D_3, Na I D_1, D_2, H_α and Ca II IRT 8542 lines.

chromospheric activity variation with the phase. In order to discuss the chromospheric activity rotational modulation and chromospheric evolution, we also collected all the chromospheric excess emission EW derived by the previous astronomers (Alekseev and Kozlova, 2002; Frasca et al., 2008; López-Santiago et al., 2010). The chromospheric excess emissions in the H_α and

Table 2
The measurements for the excess emissions of the Na I D1, D2, H alpha and Ca II IRT 8542 lines for LQ Hya.

HJD (days)	Date	Phase	EW(angstrom)							Ca II 8542/8498
24,+	day-month-year		Na I D1	Na I D2	H alpha	Ca II 8498	Ca II 8542	Ca II 8662	Li 6708	ratio
55196.9377	30-12-2009	0.56176	0.179 ± 0.006	0.118 ± 0.004	1.199 ± 0.012	0.424 ± 0.016	0.653 ± 0.049	0.541 ± 0.021	0.222 ± 0.002	1.539 ± 0.059
55197.9401	31-12-2009	0.18801	0.163 ± 0.015	0.097 ± 0.001	1.153 ± 0.001	0.440 ± 0.009	0.623 ± 0.001	0.544 ± 0.029	0.223 ± 0.006	1.417 ± 0.028
55230.8128	2-2-2010	0.72493	0.162 ± 0.011	0.120 ± 0.002	1.884 ± 0.032	0.478 ± 0.017	0.720 ± 0.019	0.653 ± 0.023	0.218 ± 0.007	1.506 ± 0.014
55231.7745	3-2-2010	0.32575	0.160 ± 0.012	0.110 ± 0.006	1.389 ± 0.008	0.467 ± 0.020	0.641 ± 0.002	0.570 ± 0.018	0.234 ± 0.008	1.371 ± 0.054
55231.9496	3-2-2010	0.43514	0.177 ± 0.008	0.125 ± 0.013	1.312 ± 0.019	0.455 ± 0.008	0.633 ± 0.001	0.532 ± 0.019	0.247 ± 0.005	1.391 ± 0.021
55232.7825	4-2-2010	0.95549	0.161 ± 0.018	0.091 ± 0.010	1.261 ± 0.010	0.444 ± 0.014	0.626 ± 0.013	0.528 ± 0.004	0.226 ± 0.005	1.410 ± 0.015

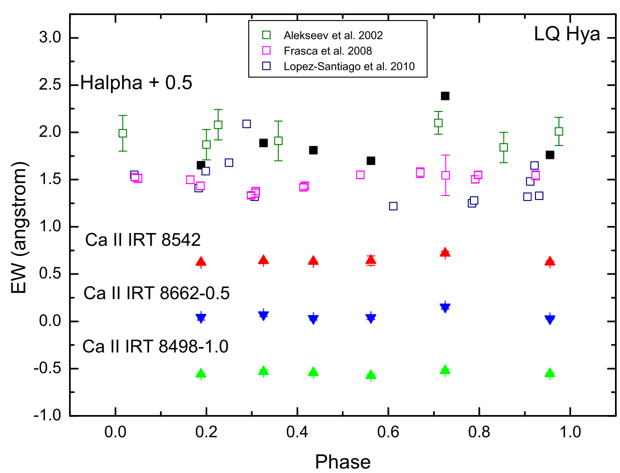

Fig. 2. The EWs of the excess emissions of LQ Hya vs. orbital phase for the H alpha and Ca II IRT IRT lines. The solid points represent our data.

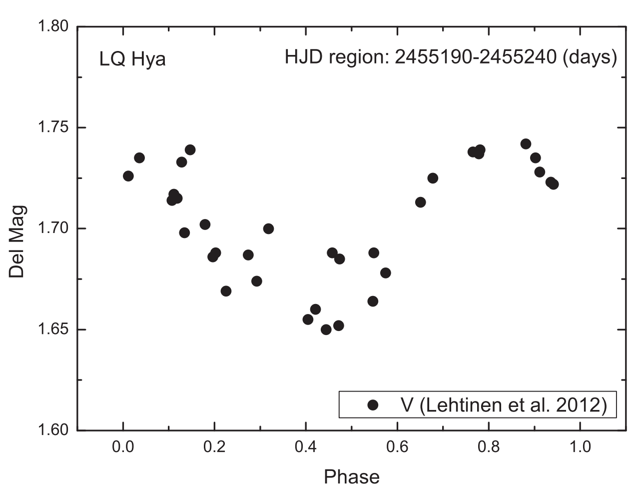

Fig. 3. The V band light curve of LQ Hya in HJD 2,455,190–2,455,240 dataset (Lehtinen et al., 2012).

Ca II IRT lines are plotted vs. the phase in Fig. 2. As can be seen from the Fig. 2, we found the data were dispersed in the different seasons, which might be explained by the chromospheric evolution. Because the Na I D_1, D_2 emissions are the weakest of the optical chromospheric indicators and they could be affected by the presence of spot regions (e.g., Andretta et al., 1997; Zhang and Gu, 2008), we did not discuss the rotational modulation in the Na I D_1, and D_2 emissions. As for our data, it seems that there is also a weak rotation modulation of chromospheric activity in the Ca II IRT and H_α lines. The longitudes of all the H_α and Ca II IRT enhanced emissions were consistent around the phases 0.3 and 0.7. However, the value of EW of the H_α line at phase 0.7 is bigger than the remaining values, which might be due to the small flare event or strong plage.

We collected the simultaneous photometric observation by Lehtinen et al. (2012) and plotted the data around the HJD region 2,455,190–2,455,240 days in Fig. 3. It can be seen from Fig. 3 that there is a rotational modulation in the V light curve. When comparing the contemporaneous optical high-resolution spectra and the V-band photometry from Lehtinen et al. (2012), we found that there is a weak anti-correlation of photospheric starspot activity and chromospheric emissions for LQ Hya. The phase of enhanced H- emission is close to that of the contemporaneous photometrically-detected starspots (especially the 0.3–0.4 phase). The anti-correlation of light curves and chromospheric diagnostics indicates chromospheric plages spatially associated with the spots. A similar phenomenon was also found in the other chromospheric active stars, such as V889 Her (Frasca et al., 2010); Ap 149 (Fang et al., 2010); EY dra (Korhonen et al., 2007); PW And (López-Santiago et al., 2003); HK Lac (Biazzo et al., 2006); II Peg (Frasca et al., 2008); and V383 Lac (Biazzo et al., 2009).

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