Astron. Astrophys. 319, 211–224 (1997)

ASTRONOMY AND ASTROPHYSICS

Environments of active close binaries

II. GK Hydrae and TY Pyxidis

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Received 27 February 1996 / Accepted 31 May 1996

Abstract. High-resolution spectroscopic observations were obtained for two eclipsing active close binary systems, GK Hydrae and TY Pyxidis. For GK Hya excess emission was observed in the Balmer lines and Mg I b lines while TY Pyx showed excess emission in the Balmer lines and Ca II H&K lines. The emission from GK Hya arises from a global phenomenon associated solely with the secondary component. The lack of significant He I D_3 excess absorption and an analysis of the flux ratio in the Balmer lines suggest that the emission originates in prominence-like material seen off the limb of the star. A marginal broad excess absorption band centered around the Balmer emission peaks may be caused by this material absorbing the stellar continuum against the disk with high (350 km s^{-1}) line-of-sight turbulent velocities. The inference that plage-like regions and associated star-spots are not substantial on this star is in agreement with the lack of spot modulation in the photometric light curve. For TY Pyx the majority of the Hβ excess and a larger proportion of the Ca II core emission could be attributed to a global phenomenon on the primary. Analysis suggests that very large volumes are responsible for the emission, however, there is no observational evidence for the existence of discrete extended structures around TY Pyx.

Key words: star: binaries: spectroscopic – stars: GK Hya; Ty Pyx – stars: activity – stars: chromospheres - stars: magnetic field

1. Introduction

Recently interest has been generated in the existence of cool coronal material similar to solar prominences surrounding either single active stars or the active components of binary systems. AB Dor is a well-studied single K0 dwarf for which Robinson & Collier Cameron (1986) found evidence of prominence-like condensations of mainly neutral material trapped in corotation by the dynamo-induced magnetic field. The variability in these transient Hα features (see also Collier Cameron et al. 1990) is consistent with a series of clouds crossing the stellar disk and these are thought to consist of cool filamentary structures. Recently Byrne, Eibe & Rolleston (1996) found prominence-like material embedded in the hot corona of the rapidly rotating dMe flare star HK Aqr which however appeared to form below the corotation radius. Other single active stars also show clear evidence of circumstellar prominences (Collier Cameron & Woods 1992).

Binary stars have also been the subject of intense scrutiny for the existence of features analogous to solar prominences. In such stars (for example RS CVn binaries; Hall 1976) excess absorption features are commonly seen in the continuum of the non-active star as extended material from the active companion overlies the stellar disk. Hall et al. (1990) reported an unusual excess Balmer line absorption feature near primary eclipse in the SS Boo system which was attributed to an extended region of 4-4.6$R_\odot$. Following this Hall & Ramsey (1992) surveyed 10 RS CVn systems and reported stable prominence-like material corotating with either the primary or secondary stars in eight of their targets. This study concluded that amongst eclipsing RS CVn stars prominence material is a common feature.

Some theoretical studies have been performed concerning the observation of prominence-like material in active stars. Buzasi (1989) developed an NLTE radiative transfer model to derive values of the Balmer equivalent width ratio (EW$_{H_\alpha}$/EW$_{H_\beta}$) in spectra corrected for the underlying photosphere. These results showed that low ratios ($\sim$ 1-2) could be achieved in both plage-like and prominence-like structures viewed against a stellar disk but that values of $\sim$3-5 could only be achieved in prominences seen off the limb of the star. A similar conclusion was reached by Heasley & Mihalas (1976) who considered detailed models of quiescent solar prominences. Such predictions have been confirmed observationally by Landman & Mongillo (1979) who found high ratios in solar prominences seen at the limb and by Chester (1991) who found ratios $<$ 2 in solar plage regions. In RS CVn binaries high ratios as-

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sociated with prominences are often found (Newmark 1990; Huenemoerder & Barden 1986).

The observational evidence for cool coronal material around active stars is still very sparse but is significant in that it is the remaining solar-like phenomenon to be confirmed in such objects. Such stellar features are found to be much larger than their solar counterparts (Hall & Ramsey 1994; Byrne, Eibe & Rolleston 1996) and may well extend beyond the component Roche lobes into regions where they are no longer magnetically confined. They therefore have important implications for mass and angular momentum loss in active stars. They further suggest that there exists cospatial plasma with significant emission measure at both optical and X-ray wavelengths (since active coronae are readily observed in the X-ray regime). The details of prominence formation on this scale is an interesting field of study, however, the unambiguous optical identification of coronal structures in active late-type stars, and in particular close binaries, is still required.

We have instigated a program of research in this field using a small sample of RS CVn binaries. In a recent paper (Gunn & Doyle 1996, Paper I) we considered in detail the technique of spectral subtraction and its application in the search for prominence-like material surrounding the active sub-giant components of close binaries. In that paper we presented and discussed our results for the highly active star ER Vulpeculae where we found good evidence for substantial plage-like material overlying the stellar surface and no evidence of extended structures. In the present paper we present our analysis of two further binary systems, GK Hydrae and TY Pyxidis. We summarize observations to date for these stars, present our observational data, briefly review the spectral subtraction technique and present our results and interpretation for these systems.

2. GK Hydrae and TY Pyxidis

GK Hydrae is an eclipsing binary of the RS CVn type with an orbital period of 3.587 days and consists of an F8 primary and a G8 IV secondary of radii $1.51R_\odot$ and $3.39R_\odot$ (respectively) with a separation of about $6.8R_\odot$. Note that in this paper we term the presumed hotter component as the primary. This corresponds to the primary star being eclipsed at phase 0.0. Oliver (1974) noted Ca II H and K emission from the cooler component of GK Hya. Hall (1976) classed the system as an RS CVn based on these observations and the wave distortions seen in the optical light curve presented by Popper (1974). Popper (1980) lists many of the properties of this system.

The available data for GK Hya is sparse and consists mainly of optical photometry. *uvby*β photometry was provided by Reglero et al. (1987) while Scaltriti et al. (1993) observed anomalous polarisation in the R band in their survey of UBVRI linear and circular polarisation from RS CVns. The most comprehensive study of the system is by Popper (1990) who analysed spectroscopic data to determine the orbital parameters. Based on data provided by Hall & Kreiner (1980) and Popper & Dumont (1977) he shows that the primary eclipse is total, deduces the relative intensity weights of the system and discusses the spectral types. Popper & Dumont (1977) and Caton (1986) present photometry which shows intrinsic variability although no clear photometric wave distortion is found for the system. The details of surface features and the circumstellar environment are therefore unknown and no detailed spectroscopic study has yet been performed. As in other RS CVn systems ultraviolet excesses are present for both components of GK Hya, about 0.07 magnitudes for the primary and 0.1 magnitudes for the secondary in U-B relative to B-V. The colours are consistent with the spectral types of F8 and G8 IV (Popper 1990).

The 6-cm radio continuum emission from GK Hya has been measured at $\leq$0.4 mJy by Morris & Mutel (1988) and at 1.04 mJy by Drake, Simon & Linsky (1989). The radio emission is therefore highly variable. The system was apparently not detected in the *Einstein* IPC Slew Program (Drake, Simon & Linsky 1992). However, Walter & Bowyer (1981) give an X-ray luminosity of 7.9 10^{30} erg s^{-1} based on their *Einstein* observations. More recently Dempsey et al. (1993) measured $L_X <$1.54 10^{30} erg s^{-1} using data from the All Sky Survey phase of the ROSAT mission.

TY Pyxidis is an eclipsing RS CVn-type binary with an orbital period of 3.199 days and consists of two almost identical G5 IV stars of radii $1.59R_\odot$ and $1.68R_\odot$ at a separation of about $24.5R_\odot$. TY Pyx is slightly evolved and the secondary star is earlier than usual for RS CVns. The system was first discovered to be an eclipsing variable by Strohmeier (1967). Popper (1969) found Ca II H and K emission lines as well as stellar absorption lines from both components. There are few detailed spectroscopic studies of TY Pyx other than that of Xuefu & Huisong (1987) who observed Hα absorption from the system and Andersen & Popper (1975) who presented the first radial velocity curve of the system and determined the physical properties. Montes et al. (1995a) recently observed excess Hα emission from both components of the system with the stronger emission from the primary component. Andersen et al. (1981a) presented an excellent discussion of the problems associated with the evolutionary status of TY Pyx as well as giving a four-colour photometric solution. Photometry for TY Pyx has been provided, amongst others, by Surendiranath, Rao & Sarma (1978), Hoffman (1978), Andersen et al. (1981b), Rao & Sarma (1981), Caton (1986), Reglero et al. (1987) and Allen et al. (1993). This binary appears to be a predictable system with no apparent period changes observed. Caton (1986) analysed UBV photometry which revealed a distortion wave in the light curve with an amplitude of a few hundredths of a magnitude which was however comparable with the errors and therefore inconclusive. He also found little correlation between the wave phases in different wave-bands. Rao & Sarma (1981) also found no evidence for a distortion wave. It is therefore unclear whether TY Pyx has observable surface features.

Many authors have attempted to measure the radio continuum emission from TY Pyx. Vaughan & Large (1987) did not detect the system above 5 mJy using the Molonglo Observatory Synthesis Telescope (MOST) at 843 MHz and Collier Cameron et al. (1982) did not detect it above 10 mJy at 5 GHz with the Parkes 64-m dish. Slee et al. (1987) and Owen & Gibson (1978) both failed to detect the system in their radio surveys at 6-cm. Florkowski et al. (1985) gave an upper limit of 1 mJy while Morris & Mutel (1988) detected it at the 0.7 mJy level with the VLA. Stewart et al. (1988) gives the 8 GHz flux as 4 mJy. Fox et al. (1994) studied the system at numerous frequencies and found that the source showed no evidence of radio flares on a time-scale of a few hours or less. However, they did find flux variations of up to a factor of three on consecutive days.

TY Pyx has also received some attention in the X-ray regime. Drake, Simon & Linsky (1992) report that it was not detected in the *Einstein* IPC Slew Program. Dempsey et al. (1993) measured the X-ray flux at $L_X = 4.63\ 10^{30}$ erg s^{-1} for each component using ROSAT All Sky Survey data. Pasquini, Schmitt & Pallavicini (1989) modeled EXOSAT spectra and determined a single component thermal plasma corona at a temperature of $2.2\ 10^{7}$ K. Using EXOSAT observations in the photon energy ranges 0.05–2 keV and 1–30 keV Culhane et al. (1990) modeled the X-ray light curve of TY Pyx. They found differing temporal evolution at each wave-band which indicated the presence of two distinct X-ray emission regions associated with the bimodal temperature distribution. The high temperature component was found to be at least as large as the binary separation while the lower temperature component underwent periodic primary and secondary eclipses.

Simon & Fekel (1987) observed TY Pyx with the IUE and used chromospheric and transition region UV emission lines in a study of the rotation-activity correlation. Fernandez-Figueroa, De Castro & Gimenez (1985) and Fernandez-Figueroa, Sedano & De Castro (1986) presented measurements and analysis of transition region emission line fluxes (most notably the Mg II lines) from IUE observations of TY Pyx and found a good correlation with the X-ray luminosity. These spectra show very well-defined emission features from low-ionization (e.g. O I) to high-ionization (e.g. N V) species. Danezis, Antonopoulou & Theodossiou (1993) present a comprehensive analysis of all IUE spectra for TY Pyx and demonstrate the existence of a weak absorption shell and a variable Mg II emission structure which appears to be phase-dependent. Antonopoulou (1983) studied TY Pyx using JHK infrared photometry in an attempt to find evidence of circumstellar material and light curve distortions. Wave-like distortions were found to be present which were attributed to a region of extreme star-spot activity but no conspicuous infrared excess was observed.

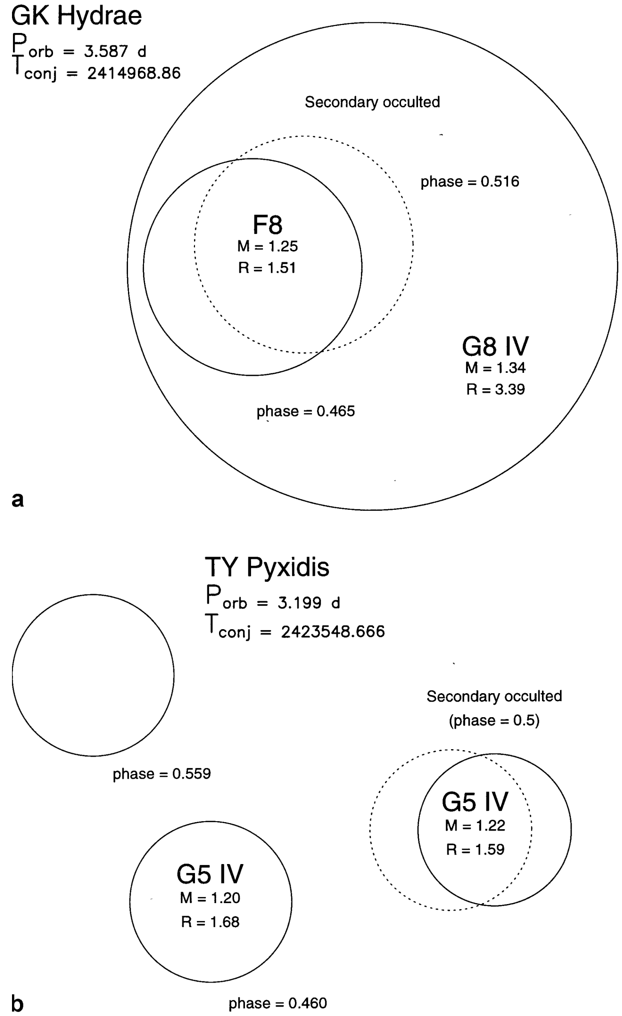

Fig. 1a and b. Schematic representation of the geometry of the binary systems during the spectroscopic observations. For GK Hydrae **a** the first spectrum was taken at phase 0.465 and the final spectrum at phase 0.516 (dotted disk). The primary disk is completely within that of the secondary during these observations. The mid-eclipse spectrum occurs at HJD 2449381.0638. Phases were calculated using the ephemeris and period of Hall & Kreiner (1980). For TY Pyxidis **b** spectra begin at phase 0.460 and end at phase 0.559, well away from eclipse contacts. At phase 0.5 the secondary disk is occulted by the primary (dotted disk). The mid-eclipse spectrum occurs at HJD 2449378.0822 and phases were calculated using the period and time of conjunction given by Andersen & Popper (1975) and Andersen et al. (1981a) respectively. All masses and radii are in solar units.

3. Observations and data reduction

High-resolution spectroscopic data were obtained during a 4-night observing run in January 1994 carried out with the University College London Échelle Spectrograph (UCLES) located on the Anglo-Australian 3.9-meter Telescope (AAT) at the Anglo-Australian Observatory at Siding Spring, Australia. Descriptions of the telescope are given by Wampler (1975), Gascoigne (1975) and Whelan (1976). The UCLES instrument (Walker & Diego 1984; Walker & Diego 1985) is located at the f/36 coudé focus of the telescope giving good stability of the spectrograph; random shifts in calibration over one hour are expected to be no worse than 0.005 pixels or 15 m s^{-1}. The échelle spectra were recorded on a Tektronix CCD with a pixel size of 24μm and dimensions of 525 × 1024 pixels. The resolving power of the spectrograph is approximately 50,000 which corresponds to a wavelength resolution of 0.13Å or a velocity resolution of 4.3 km s^{-1} at Hα (6562.852Å). Observations were timed to encompass the eclipses of the targets but due to scheduling constraints only secondary conjunctions were observed. In total 52 spectra of GK Hya were obtained with integration times in the range 50–300 seconds over the wavelength range 4620–7020Å.

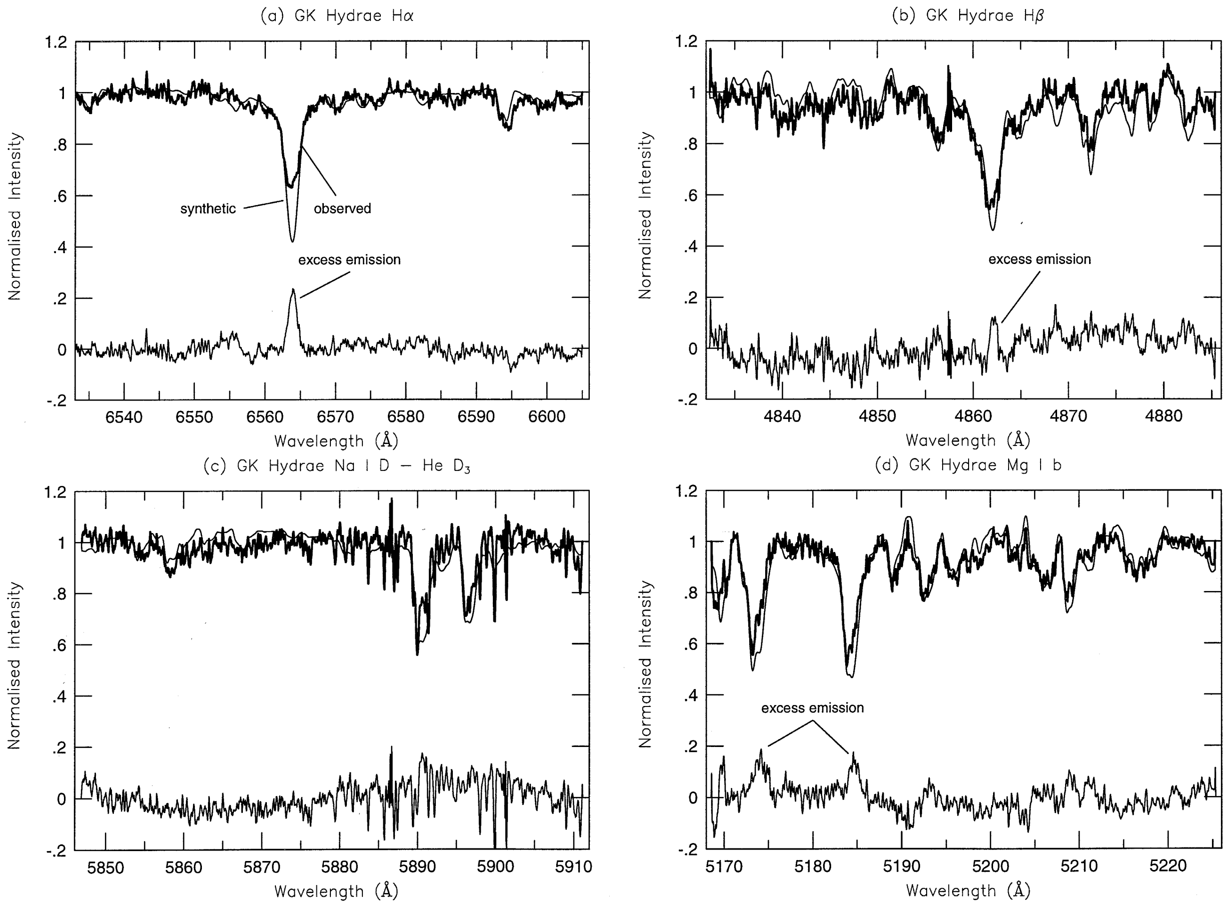

Fig. 2a–d. Observed, synthetic and subtracted spectra for spectral orders containing activity-sensitive lines for a single GK Hydrae spectrum (phase 0.465). Lines shown are **a** Hα, **b** Hβ, **c** Na I D and He I D_3 and **d** Mg I b. Bold lines indicate the observed spectra with overlying thin lines showing the synthetic spectra. The zero-continuum data are the resulting subtracted spectra showing excess emission/absorption features.

For TY Pyx 114 spectra were taken with integration times in the range 60–180 seconds over the range 3850–4970Å. Fig. 1 shows schematic representations of the binary systems during the observations. The atmospheric conditions remained reasonably good during the observations. The estimated seeing generally remained in the range 1–3 arcseconds. On occasion the slit size was varied to account for the extinction caused by thin cirrus cloud but this also increased the background lunar counts for some exposures. As well as the target binaries, a small set of standard stars were also observed to act as spectral standard stars or reveal the extent of atmospheric absorption lines; these stars were HR 2637 (HD 52619), HD 53590, HD 55685 and HD 63868.

CCD reduction and spectrum extraction and calibration was performed with IRAF[1]. After bias subtraction, image trimming and flat-fielding, spectral apertures were defined by reference to bright star images and object spectra extracted. Spectra for GK Hya consisted of 17 orders and for TY Pyx consisted of 33 orders. Th-Ar calibration frames were extracted and lines identified across all orders (typically 200 lines were defined). Wavelength calibrations did not drift by more than 0.02Å and the extracted spectra typically had signal-to-noise ratios in excess of 50. Normalisation to unity of each spectrum was performed individually by fitting a spline function across pre-defined continuum points. This was to ensure an objective normalisation to the entire data set. Some spectral orders were corrected for the presence of atmospheric lines by reference to rapidly-rotating B-star spectra.

[1] IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation (USA).

4. Spectral subtraction

We have used the spectral subtraction procedure described in detail in Paper I in the analysis of the spectroscopic data for TY Pyx and GK Hya. This is a method of estimating the chromospheric contribution in active lines and involves simulating the *inactive* spectrum of the target star and performing a linear subtraction from the observed data. In practice we synthesize the binary spectrum by combining two spectra of stars which resemble the target components in all respects other than in their apparent levels of activity. These essentially non-active stars

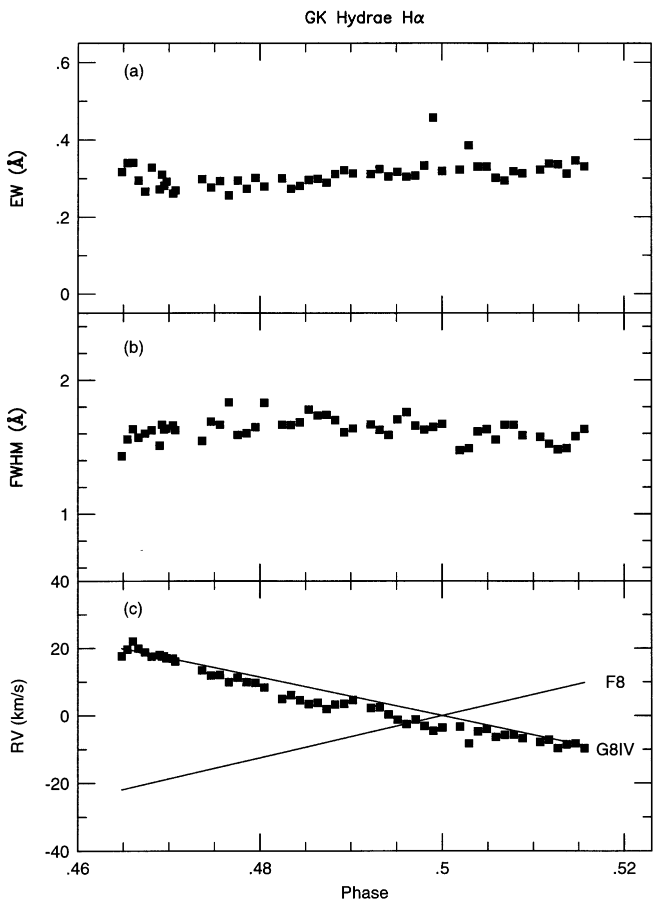

Fig. 3a–c. Results of the analysis of the subtracted Hα emission line from GK Hydrae. The upper panel shows the variation in EW, the middle panel the variation in FWHM and the bottom panel the radial velocity of the emission compared to the RV curves of each component.

we refer to as *standards*. Any manifestation of activity is then visible in the subtracted spectrum as emission or absorption features above or below the zero continuum level. Similar techniques have been used by Herbig (1985), Young et al. (1989), Thatcher & Robinson (1993) and Montes et al. (1995a,b). The reader is referred to Paper I for a complete discussion of the application of spectral subtraction in this study. We emphasize here that an iterative matching technique (e.g. Barden 1984) is not used in this study to derive radial/rotational velocities and intensity weights due to the eclipse nature of the observations. Instead, geometrically-corrected, T_{eff}-derived intensity weights and *model* radial velocities are used directly. Radial velocities are provided for GK Hya by Popper (1990) and for TY Pyx by Andersen & Popper (1975). Gunn et al. (1996) recently confirmed the ephemeris and velocity semi-amplitudes of these systems. The final subtracted spectra were analysed by measuring excess absorption or emission features in the active lines of the target stars.

As will be seen in the ensuing sections some problems were encountered in matching the normalisations of target and template stars (cf. Figs. 2 and 6). This is particularly prevalent in the blue region and stems from the fact that common continuum points do not exist for two stars of greatly differing rotational velocities, at high dispersion and with a profusion of absorption features. However, the normalisation mismatches simply reveal a smoothly varying background while detailed features usually cancel well. We believe that the isolation of excess features is still possible in these cases although we stress the risks of quantitative interpretation. We also concur that spectral subtraction is a difficult technique to apply in the blue region.

5. Results

5.1. GK Hydrae

The spectral standard stars chosen to form a match for the GK Hydrae system were HD 52619 (F8 V) and HD 53590 (G8 IV). The velocities of these stars were checked by locating the positions of selected stellar lines. Based on this analysis the correction for the systemic motion of the spectral standards is consistent with the observational data. Agreement between the wavelength calibrations of spectral standards and target spectra were checked by measuring the positions of several atmospheric lines visible in all spectra. The maximum deviation was no more than 0.01Å.

Spectral synthesis was performed for the active orders in the GK Hydrae spectra. The lines analysed were Hα and Hβ, the Na I D and He I D_3 lines and the Mg I b lines. Fig. 2 shows examples of the fits to these lines for a representative spectrum. Bold lines are the observed spectra and thin lines the synthetic fits. Also shown in these diagrams are the subtracted spectra. In orders containing no activity-sensitive features good cancellation of lines was achieved. Both Balmer lines and the Mg I b lines show a clear excess emission feature. Hα also appears to be embedded in a very broad excess absorption background. Due to the slight normalisation mismatch for the Na I D order, noise and small atmospheric lines it is difficult to measure the emission feature in the sodium lines but it is quite clear that excess emission is present. There is a slight indication of some excess absorption in the He I D_3 line but this is not significantly above the noise. The feature is however clearly present. Small atmospheric absorption profiles in this order which were not removed well in the data reduction make it difficult to draw any firm conclusions from the results.

Fig. 3 shows the results of measurements of the subtracted Hα emission profiles from GK Hya. There does not appear to be much variation in the width or peak intensity in Hα which suggests the emission is originating on a single component of the binary. The equivalent width of the emission does not change during the observations suggesting that the emission mechanism remains stable. The FWHM also appears to undergo no significant changes again implying that the emission is from a single component. Measurement of the radial velocity of the emission (Fig. 3c) confirms that it is originating solely on the secondary component of the system. Similar results for the Hβ and Mg I b lines (at 5172.68 Å and 5183.61 Å) are shown in Figs. 4 and 5 respectively. Hβ is in emission in the subtracted profile and also seems to be embedded in a broad absorption background.

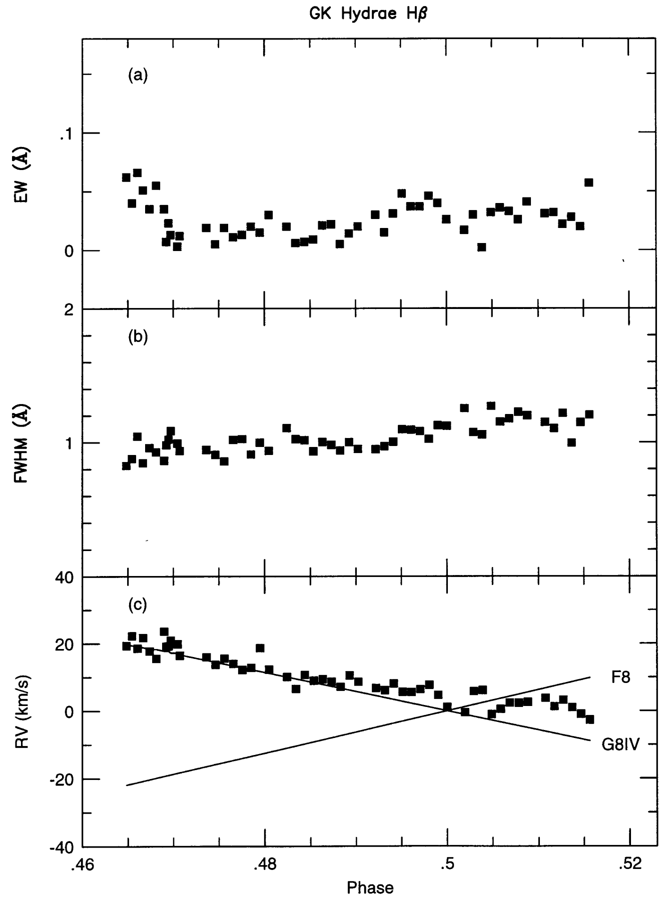

Fig. 4a–c. Results of the analysis of the subtracted Hβ emission line from GK Hydrae. EW, FWHM and radial velocities are shown.

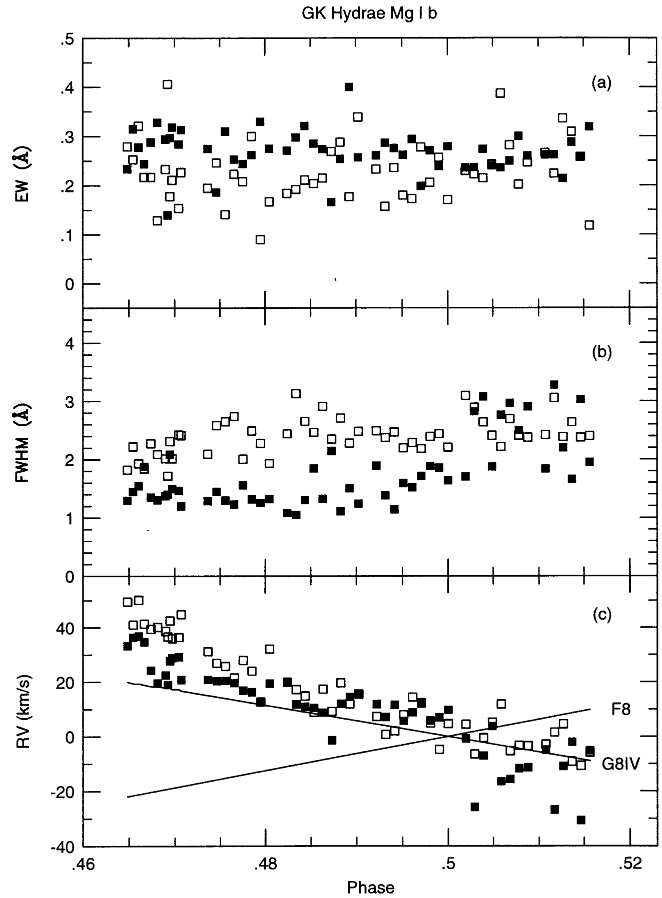

Fig. 5a–c. Results of the analysis of the subtracted Mg I b emission lines from GK Hydrae. EW, FWHM and radial velocities are shown for the λ5172.68 line (filled squares) and the λ5183.61 line (open squares).

The emission equivalent width and FWHM does not vary with phase (although the FWHM may increase slightly with phase) and the velocity of the emission is firmly associated with the secondary component. For the two Mg I b lines the measured results have a large dispersion but clearly the emission is again associated with the secondary component.

5.2. *TY Pyxidis*

The spectral standard star chosen to form a match for both components of the TY Pyxidis system was HD 55685 (G5 IV). Checks on velocities and wavelength calibrations were made on the spectral standard using the same procedures as for GK Hya.

Spectral synthesis was performed for the active orders for all TY Pyxidis spectra. The lines analysed were Hβ (λ4861.33), Hγ (λ4340.47), Hδ (λ4101.74) and the Ca II H and K lines (λ3968.47 and λ3933.66). Fig. 6 shows examples for some of these orders of the synthetic spectra formed for one TY Pyx spectrum. Bold lines are the observed spectra and thin lines the synthetic spectra. Also plotted on these diagrams are the subtracted spectra. Some inactive orders in this part of the spectrum gave imperfect cancellation of lines. It should be noted immediately that all Balmer lines other than Hβ did not show an excess absorption or emission feature above the noise in the subtracted spectrum or which could be unambiguously measured above other apparently uncancelled lines. A good example of this is shown in Fig. 6b for the Hγ line. This order also shows the severe effect of problems with continuum definition. Hence for Balmer lines other than Hβ it is not possible to make any statements other than that they are present in absorption with rotationally broadened depths consistent with the spectral types. As can be seen however the Hβ line and the Ca II H and K lines all show significant excess emission features. This indicates that Hβ has significant filling-in of the global absorption profile over and above that expected for standard stars, while the Ca II lines display core reversals, the definitive indicator of chromospheric activity. Although there are normalisation mismatches for the Ca II lines there may be an additional source of excess absorption across the entire profile. This is apparent for the K line which shows a continuum apparently well matched in all parts of the spectrum other than surrounding the emission core.

Fig. 7 shows the results of measurements on the subtracted Hβ emission line of TY Pyx. The Hβ line seems to be embedded

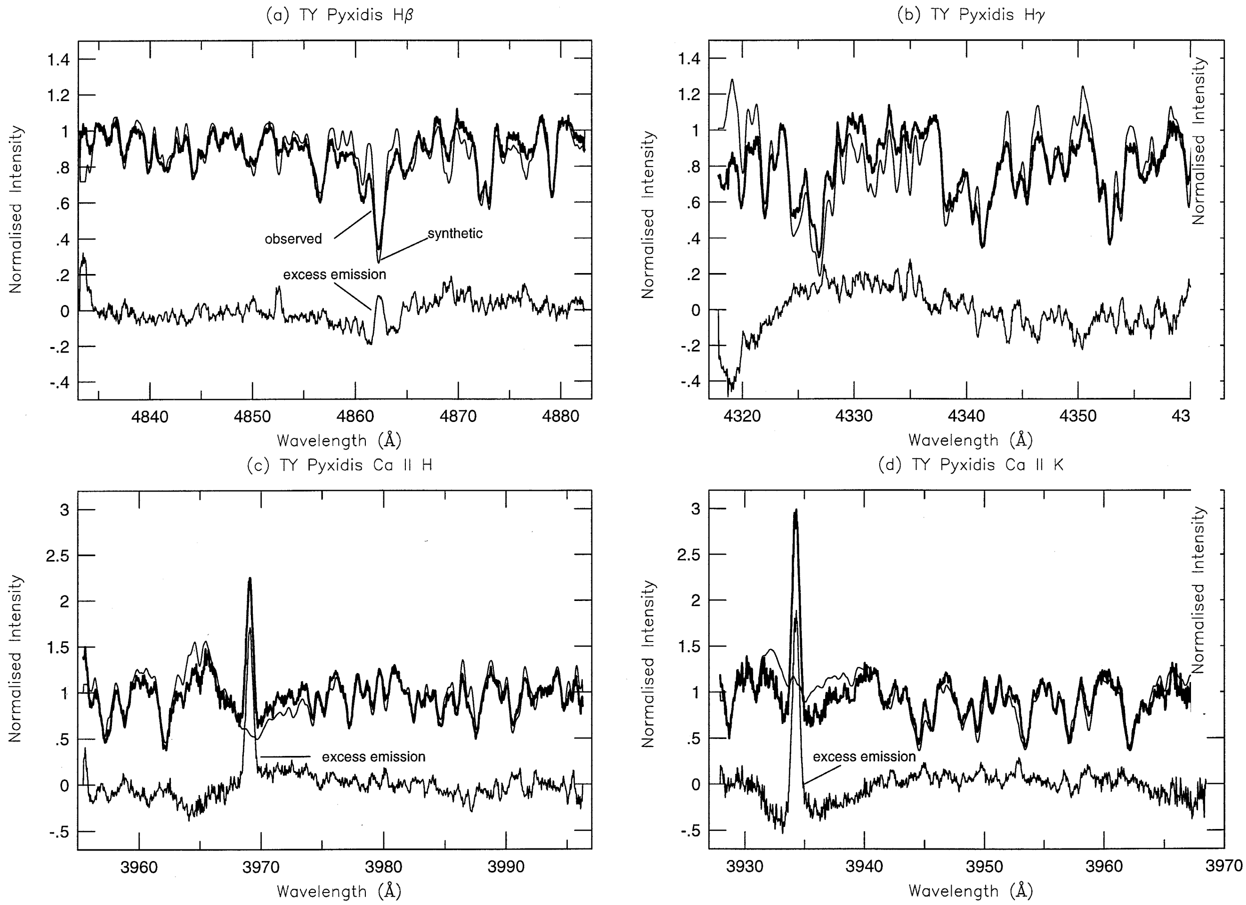

Fig. 6a–d. Observed, synthetic and subtracted spectra for spectral orders containing activity-sensitive lines for a single TY Pyx spectrum (phase 0.500). Lines shown are **a** Hβ, **b** Hγ, **c** Ca II H and **d** Ca II K. Bold lines indicate the observed spectra with overlying thin lines showing the synthetic spectra. The zero-continuum data are the resulting subtracted spectra showing excess emission/absorption features.

in a broad absorption component. Measurements are difficult on this feature since it is not significantly above the noise but its position would indicate that it is not coincident with the emission feature and therefore probably due to normalisation problems. This absorption is present throughout the observations which are not always of an eclipsing nature. Therefore the absorption cannot be due to the atmosphere of one of the stellar components. However, the absorption appears to be symmetrical with a maximum displacement of about 1.5Å, which corresponds to approximately 100 km s^{-1} at Hβ. Another possibility for this feature is a mismatch in spectral types giving unequal flux levels in the wings of the Balmer lines.

Fig. 7a shows the equivalent width (EW) measurements for the excess Hβ emission. There is some obvious variation in this quantity with phase and the line strength appears to reach a minimum shortly before the conjunction and then rises again before slowly decreasing once more. The FWHM of the emission is shown in Fig. 7b and shows evidence of a minimum during the conjunction which implies that the emission is originating in both components. Finally Fig. 7c shows the measured radial velocity of the emission feature against phase with the actual orbital velocity of the primary and secondary components plotted as solid lines. Clearly the majority of the excess emission is associated with the primary component of TY Pyx. The velocity also appears to undergo distinct, almost periodic, variations around the primary velocity. The majority of the time it appears to be skewed red-ward of the primary. Note that measurements made on spectra towards the end of the observations have been affected by a low signal-to-noise ratio caused by light cirrus during the observations. It is dubious whether these measurements could be expected to follow the consistent pattern in earlier spectra.

Fig. 8 shows results for the Ca II H & K excess emission profiles from TY Pyx. Measurements of the equivalent widths of this emission (Fig. 8a) show a very dramatic increase in the emission from these lines shortly before conjunction, the K line being the stronger. This appears to be coincident with a smaller increase in emission strength seen in the Hβ line. The FWHM variation is very smooth and strongly suggestive that the emission arises on both components of the binary. Measurements of the velocity of these profiles (Fig. 8c) show an almost constant velocity centred somewhat blue-shifted from the binary rest frame. This indicates that the Ca II lines from each component are of similar intensity so that the resulting velocity is an average of the orbital velocities of the two components. The small variation with phase indicates that the primary may be slightly more luminous in Ca II H excess emission than the secondary. Such an effect was also observed in the Ca II IRT lines in the ER Vulpeculae system (Paper I). The blue-ward shift of the overall emission suggests there may be some bulk upflow of the material associated with the Ca II H and K excess emission.

6. Discussion

6.1. GK Hydrae

6.1.1. The Hα and Hβ emission lines

The observations of GK Hydrae have revealed significant excess emission in the Balmer lines Hα and Hβ. Although there is no clear evidence for a discrete region of absorption in the subtracted profiles, both Balmer lines appear to be embedded in a broad absorption band which is *marginally* above the noise. This feature will be discussed below. Analysis of the velocity and width of these emission peaks strongly suggest that they are associated solely with the secondary (G8 IV) component which is constantly eclipsed annularly during these observations. The constancy of the EW also suggests the emission mechanism is stable over the phase of the observations (0.05). As in the case of ER Vulpeculae (Paper I) the minimal phase coverage is insufficient to reveal any flux variations with phase due to the modulation by discrete active regions. However, the velocity variations suggest the emission is due to a global phenomenon. No obvious velocity shift in the emission is visible which for ER Vulpeculae was compared to solar spicule motions.

He I D_3 absorption is absent for GK Hya, suggesting a very different chromospheric structure and emission mechanism for GK Hya than for ER Vul. To investigate this and to utilise the simultaneous observations of two of the Balmer lines the results of Buzasi (1989) may be reviewed. This study involved two simple geometries for active regions around late-type sub-giants and dwarfs. The first was a vertically oriented slab of material analogous to a solar prominence that is illuminated by the photosphere on both sides. The second was a horizontally oriented slab analogous to a solar plage illuminated only from beneath. The models considered were for solar quiescent prominences which have a source function dominated by the photosphere and Buzasi (1989) considered the theoretical ratio of Hα equivalent width to Hβ equivalent width ($EW_{H_\alpha}/EW_{H_\beta}$) expected for regions seen off the limb of the star and against the disk. The general result was that it was difficult to differentiate between plages and prominences solely on the basis of the $EW_{H_\alpha}/EW_{H_\beta}$ ratio but plage region ratios were typically 10-20% smaller than those for prominences. The highest ratios (> 8) were found only to occur for low electron densities and relatively small optical depths. The maximum attainable $EW_{H_\alpha}/EW_{H_\beta}$ ratio is about 15. Ratios smaller than about 2 can be obtained by increasing the electron density making the source function more dependent on the thermodynamic temperature. Increasing the optical depth makes Hβ emit stronger thereby also decreasing the ratio.

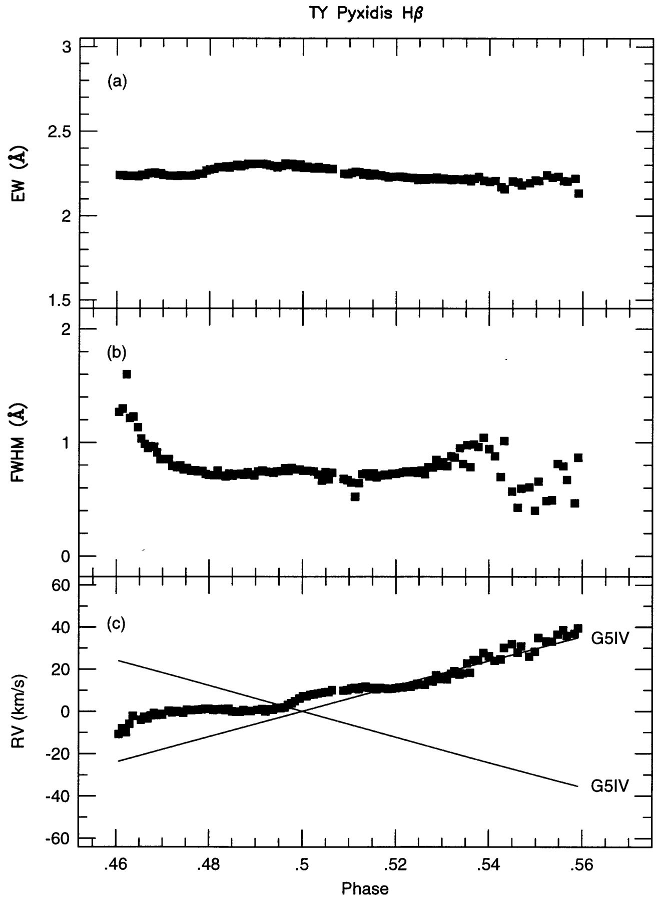

Fig. 7a–c. Results of the analysis of the subtracted Hβ emission line from TY Pyxidis. EW, FWHM and radial velocities are shown.

Overall high ratios require low densities while low ratios may be formed by high densities or large optical depths.

The above discussion is applicable for prominences seen off the limb. This is where spectral subtraction is not important because subtracting the inactive photospheric spectrum reveals the true spectrum of the prominence. Buzasi (1989) further investigated the Balmer ratios for regions seen against the disk. Excess emission in this case is only possible if the source function of the overlying material exceeds that of the photosphere which requires high temperatures and densities. For all features on the disk low ratios were found for these models. Hence to obtain high ratios the emission must be an optically thin prominence off the limb although small ratios can be either due to prominences or plages viewed against the disk. Since the density of emitting material should scale roughly with surface gravity (Buzasi 1989) suggests that main-sequence stars will tend to have plage regions rather than prominences. Similar conclusions concerning the $EW_{H_\alpha}/EW_{H_\beta}$ ratios from quiescent solar prominences were given by Heasley & Mihalas (1976) who presented a theoretical formulation of the problem.

These predictions are in fact borne out by solar observations. Tandberg-Hanssen (1967) found that the $EW_{H_\alpha}/EW_{H_\beta}$ ratio is typically about 1.5 in the solar chromosphere decreasing to between 1.3 and 0.83 during solar flares. Landman & Mongillo (1979) measured high-resolution Hα and Hβ profiles in numerous off-limb quiescent prominences and found ratios between 5 and 12. For the case of plages, Chester (1991) recently confirmed ratios of less than 2 using high-resolution observations. The solar values therefore appear to be in agreement with the predictions of both Buzasi (1989) and Heasley & Mihalas (1976). EW$_{H_\alpha}$/EW$_{H_\beta}$ ratios for RS CVn systems are generally found to lie in the range 4 to 8; above the range of values typical of lower chromospheric structures but within the range typical of quiescent prominences (Huenemoerder, Ramsey & Buzasi 1990). Direct comparison between these results would imply that plage regions are not the dominant source of Balmer excess emission in the active sub-giant components in RS CVns.

The preponderance of weak plages on lower gravity cool dwarf components of RS CVns seems reasonable. Greater surface gravity and electron densities in dwarf stars will result in the enhancement of lower decrement photons and thus give lower EW$_{H_\alpha}$/EW$_{H_\beta}$ ratios. However, neutral metal lines such as Mg I and Na I which are expected to be collisionally controlled across all late-type chromospheres (including both dwarfs and sub-giants) should have similar behaviour in all RS CVn components. On the other hand the Balmer lines would be expected to behave quite differently between dwarfs and giants since collisional domination would not occur as readily in low density, low gravity atmospheres.

Using the mean excess emission EW for Hα and Hβ for GK Hya we find a ratio of EW$_{H_\alpha}$/EW$_{H_\beta}$ = 11.4. This very high value is strongly suggestive of prominence-like material off the limb of the secondary component. No discrete absorption features from such structures would be expected since the primary is occulting the secondary during these observations. If prominences are the cause of the excess emission then the velocity implies that the emission is global and therefore the prominence volume is large and evenly distributed around the star. This is a common feature in RS CVns (Chester 1991). An interesting comparison can be made between GK Hya and ER Vul (Paper I). The more active component of ER Vul is a dwarf star which seems to show evidence of a large filling factor associated with saturation of the atmosphere with low lying plage material. On the other hand the more active component of GK Hya is a sub-giant which seems to show evidence for large vertical prominences rather than plage regions. This is in excellent agreement with both observations and theoretical predictions. It is unfortunate that this difference could not be investigated further with observations of all lines of interest for both stars and by investigating excess emission and photometric variations over the full phase of the binaries.

A calculation can be performed for the approximate volume of the emitting region in Hα from GK Hya using the method outlined in Paper I. The atmospheric models of Kurucz (1979) do not extend into the region of sub-giant stars but taking a log g value of 0.0 (relative to the Sun) and an effective temperature of 5500 K the flux density at Hα is 1.89 10^6 erg s^{-1} cm^{-2} Å^{-1} which differs from the black-body flux at Hα by $< 3\%$. The corresponding luminosity at Hα for GK Hya is 1.32 10^{30} erg s^{-1}

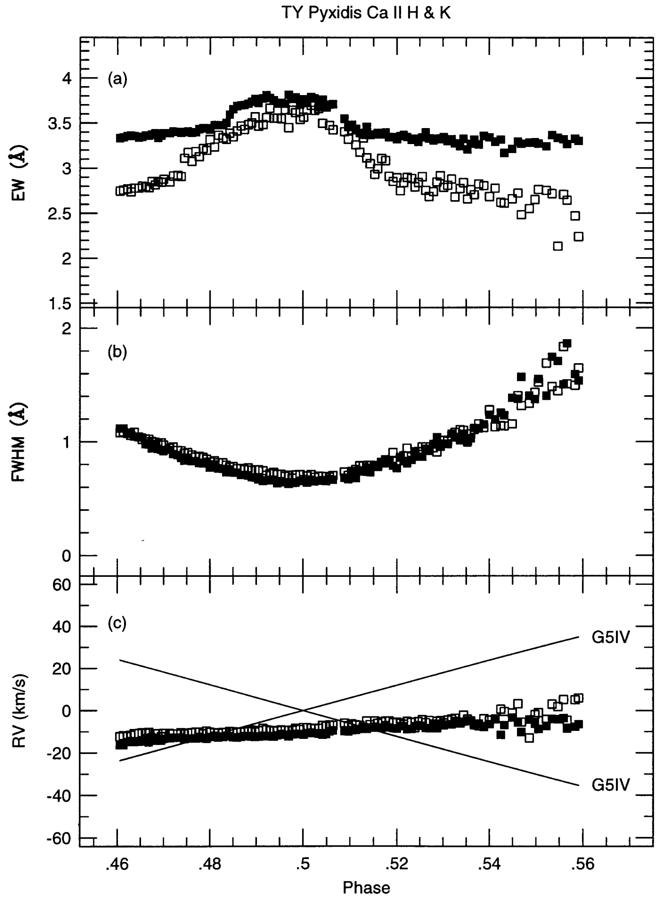

Fig. 8a–c. Results of the analysis of the subtracted Ca II H & K emission lines from TY Pyxidis. EW, FWHM and radial velocities are shown for the λ3968.47 line (filled squares) and the λ3933.66 line (open squares).

Å^{-1} assuming a radius of 3.39$R_\odot$. The mean equivalent width of the excess emission (0.31 Å) is equivalent to a luminosity of 3.1 10^{30} erg s^{-1} across the 2Å band used to define the EW. Using the same assumptions discussed in Paper I the possible range of volume for the emission region is 1.3 10^{33} - 1.6 10^{34} cm^3 and the chromospheric thickness is R_c = 0.052 - 0.56$R_\odot$. Although this is larger than for ER Vul, which may be expected for a lower gravity star showing prominence emission, it is a smaller fraction of the stellar radius. However, although prominences may be more common than plages on sub-giants it is difficult to say how their scales vary for different spectral types and luminosity classes. It is unlikely that prominences scale linearly from the solar analogy and the results here indicate that they may also not scale as an inverse square law. Other factors may also be involved since the chromospheric thickness for GK Hya (G8 IV) is much greater than that seen on sub-giants of type G5 IV and K1 IV in HR 1099 (Fraquelli 1984).

Mention has been made of the appearance of a broad excess absorption band which surrounds the Hα and Hβ emission profiles. Although it must be stressed that this feature is *not significantly above the noise*, particularly at Hβ, it does appear to exist as a slight depression in the far wings of the Balmer lines in the un-subtracted spectrum compared to the synthetic one. There is therefore reason to believe that this feature is very weak but real and hence requires explanation. The absorption is symmetric about the emission profile with a maximum extension either side of about 8Å at Hα (the measurement at Hβ is less certain) which corresponds to a maximum velocity of about 360 km s^{-1}. This absorption cannot be due to the primary component's atmosphere absorbing the secondary continuum since if we assume a co-rotating atmosphere for the primary its size would be about $25R_\odot$; much greater than the size of the secondary. Also the position of the absorption band seems to track quite closely the velocity of the secondary component. The conclusion must be that the broad absorption is arising on the secondary star.

Such an excess absorption feature has not been observed before in subtracted spectra; in fact quite the opposite has been found. Buzasi (1989) found in subtracted spectra of a number of RS CVn stars that Hα and Hβ clearly displayed broad non-gaussian excess emission wings centred generally around the emission peak and extending both to the red and blue by up to 200 km s^{-1}. Difficulty was found in ascribing this emission to a particular physical phenomenon. Stark broadening was discounted since the effect was seen more prominently in Hα than Hβ whereas Stark broadening becomes more important for higher level populations. The results implied for several systems that the chromosphere was stratified with a lower region where the Ca II IRT is formed having little vertical motion and a higher region of Balmer emission with large areas of up-flowing and down-flowing material apparently dominant over most of the region in which the Balmer line wings are formed. Observations of dMe stars have often shown an analogous symmetric or asymmetric Balmer line broadening associated with mass flows in the chromosphere (Doyle et al. 1988; Gunn et al. 1994a,b).

The observations of GK Hya may have revealed a different scenario. However, some comparisons to the solar case may be made. In strong lines such as Hα, prominences are seen in emission off the limb in the transparent solar corona. When viewed against the disk, prominences are seen in absorption (Engvold, Jensen & Andersen 1979). The secondary component of GK Hya appears to be dominated by prominence-like structures so the emission in the Balmer lines may be originating mainly in prominences viewed at the limb (where the line of sight velocity is approximately zero giving rise to an emission profile consistent with the position and rotation of the star), while prominences seen against the disk of the star are seen in absorption with a very broad line-of-sight turbulent velocity distribution. These features are all seen against the usual chromospheric absorption profile. Although velocities seen in solar quiescent prominences can be as high as 35 km s^{-1} (Engvold 1976) the velocities for GK Hya are an order of magnitude higher than this. This may not be impossible in a star with a much lower surface gravity and which is much more active than the Sun. Verification of such a model is beyond the capabilities of the present observational data. If these features are real this demonstrates that the spectral subtraction technique is a valuable method of revealing activity signatures in active close binary stars which are not normally visible in raw spectra. Another possibility for the broad absorption seen in the Balmer lines is the existence of very different lower chromospheric and photospheric temperature structures in the standard and observed stars. This would result in a mismatch in the line wings of the profiles.

6.1.2. The He I D_3 and neutral metal lines

The observations have revealed a small amount of excess absorption in the He I D_3 line from GK Hydrae but this is not significantly above the noise and therefore difficult to quantify. As discussed in Paper I, He I D_3 absorption is associated with plage regions in the solar spectrum and also, by analogy, in late-type dwarfs. These results suggest that there is a small amount of plage-like material on one of the components of GK Hya. In the light of the above discussion it seems unlikely to be associated with the sub-giant secondary but at the present level of detection it is not possible to unambiguously determine its origin or implications.

Excess emission has been detected in the neutral metal lines of Mg I b and Na I D from GK Hya although it should be noted that problems with normalisation and low signal-to-noise in the Na I D order make the detection less firm for these lines. The detection of excess Mg I emission is much firmer for the two lines covered by the observations (λ5172.68 and λ5183.61). Analysis of the velocity of the Mg I feature firmly associates it with the secondary component although the dispersion in velocity is large. The neutral metal lines are good indicators of lower chromospheric and photospheric activity (Panagi, Byrne & Houdebine 1991; Altrock & Canfield 1974). These observations confirm that there must be appreciable non-radiative heating in the lower atmosphere of the G8 IV component of GK Hya. The apparent disparity between observed Mg I and Na I lines found for ER Vulpeculae does not appear to be the case for GK Hya since weak Na I excess emission is detected. However, the lower ionization potential for Na I compared to Mg I again points to a more complex chromospheric structure or opacity effects for these lines. Detailed chromospheric modeling for the neutral lines is therefore required.

6.2. TY Pyxidis

6.2.1. The hydrogen balmer lines

The observations of TY Pyxidis have revealed significant excess emission in the Hβ line of hydrogen. Other Balmer lines were not visible above the noise in the subtracted spectra but were seen in absorption in the raw data. The subtracted Hβ emission feature appears to be embedded in a broad absorption component which is marginally above the noise. Analysis of the velocity and width of the excess emission profile shows that it originates on both components of the system although it is dominated by the primary component. Although the phase coverage of the observations ($\sim$0.1) is insufficient to reveal any flux variations with phase which can be firmly associated with discrete active regions there is a noticeable increase in EW almost centred around secondary conjunction which correlates well with variations in the Ca II lines. This increase in flux is not due to continuum variations (due to obscuration) since individual spectra were normalized independently and because the emission is clearly associated with the primary component which is not eclipsed during these observations.

Very little theoretical or observational work has been performed on the properties of Hβ emission/absorption lines in active late-type stars (Mathioudakis & Doyle 1991). This is partly because Hβ and the higher Balmer lines lie in a spectral region contaminated by many additional line blends making measurement or comparison with computed profiles difficult. However, Hβ equivalent width has been shown to be temperature dependent across the range of later spectral types (Thatcher & Robinson 1993). Also, as expected, Hβ shows qualitative behaviour similar to Hα with an increase in chromospheric activity. As activity levels increase, the Hβ line depth increases, then slowly fill in and become pure emission lines in only extremely active stars. This is in agreement with the theoretical results of Cram & Mullan (1979), Cram & Giampapa (1987) and Houdebine, Doyle & Koscielecki (1995). Hα however fills-in faster than Hβ with increasing activity since the collisional filling of the n=3 state is greater than that of the n=4 state (higher energy). Unfortunately the present observations have not encompassed the Hα line in TY Pyx so it is not possible to investigate Balmer line correlations. Neither is it possible to study the implications of the Balmer decrement (EW$_{H_\alpha}$/EW$_{H_\beta}$) which in the case of GK Hydrae provides evidence for the presence of prominence-like material in the environment of that system.

Using the Hβ excess emission some simple calculations can be performed regarding the approximate volume of the emitting region. Assuming a log g value of 0.0 (relative to the Sun) and an effective temperature of 5500 K for TY Pyx then atmospheric models of Kurucz (1979) give the flux density at Hβ as approximately 2.16 10^6 erg s^{-1} cm^{-2} Å^{-1}. This differs from a blackbody flux at 4861Å by $< 6\%$. The corresponding luminosity at Hβ for the TY Pyx primary is 3.32 10^{29} erg s^{-1} Å^{-1} assuming the radius is $1.59 R_\odot$. The mean equivalent width of the excess Hβ emission is 2.31Å and is equivalent to a luminosity of 1.4 10^{30} erg s^{-1} across the 2Å band used to define the EW. We use the same assumptions discussed in Paper I. Careful inspection of the results of Burgess (1958) reveals that the relation for the volume emissivity for the Hβ line is

$$j = 4.9 \times 10^{-24} n_e^2 T^{-1/2} \log \left\{ \frac{I_H}{kT} \right\}, \quad (1)$$

where I_H is the hydrogen ionization energy, n_e is the electron density and T the temperature. Assuming the Hα and Hβ lines are formed over approximately the same ranges of electron density and temperature then the possible range in the volume of the emission region is 1.6 10^{33} to 1.9 10^{34} cm^3 and the chromospheric thickness is R_c = 0.25 - 1.57$R_\odot$. These values are by far the highest for any of the systems studied optically in this work. Larger values of R_c may be expected for sub-giant stars with lower surface gravities such as those in TY Pyx. Such high values may indicate several scenarios. Firstly the emission from the secondary has been ignored in this calculation and the assumption made that the primary is the source of the excess. This is clearly not the case since the FWHM of the profile changes through the observations. In fact Hα observations of TY Pyx by Montes et al. (1995b) suggest the secondary contributes about 40% of the Balmer line flux to the spectrum. However, such a correction for the affect of the secondary still requires the emission volume for the primary to be in the range 0.2 - 1.3R$_\odot$. It is therefore possible that the excess in Hβ is originating in very large volumes of prominence-like material surrounding the primary star or that it arises in a region of much higher electron density and temperature than has been assumed. It may be remarked that no firm evidence of extended prominence-like material is seen in the subtracted spectra. Unfortunately it has not been possible to test these possibilities since no comparison with Hα can be made. It can be noted that Montes et al. (1995a) observed excess emission in Hα for TY Pyx which was significantly stronger in the primary component. The observations to date therefore are consistent in attributing a high degree of Balmer line core activity in the primary component of TY Pyx.

The broad excess emission band surrounding the Hβ line in TY Pyx is very similar to that seen in both Hα and Hβ in GK Hydrae. For TY Pyx the spectral subtraction technique proved more difficult due to the imperfect cancellation of photospheric features. Hence the detection of an excess absorption band is less convincing but may have a similar explanation. This feature is apparently symmetric around the emission profile with a maximum extension either side of about 1.5Å which corresponds to a velocity shift of about 100 km s^{-1}. This absorption cannot be due to the primary component's atmosphere absorbing the secondary continuum since if a corotating atmosphere is assumed for the primary then its size would be 6.3$R_\odot$; much greater than the size of the secondary. This feature may also indicate the presence of prominence-like material absorbing at the far wings of Hβ with a very high turbulent vertical velocity distribution. Such a scenario may be consistent with the implication that the emission volume on the TY Pyx primary component is very large.

6.2.2. The Ca II H & K lines

The presence of Ca II (λ3933.66 K and λ3968.47 H) emission cores in solar and stellar spectra have been the primary indicators of chromospheric activity. The emission cores in late-type stars are generally many times stronger than in the Sun and are believed to represent high degrees of non-radiative heating in plage-like regions and in the chromospheric network. In addition to their ease of observation the Ca II lines are important because their source functions are collisionally dominated (Thomas 1957; Jefferies & Thomas 1959) and so are sensitive indicators of the electron density and temperature in the line forming regions.

Even though Ca II line emission is a valuable diagnostic in active late-type stars its analysis for double-lined active binary stars such as most RS CVns is complicated by the presence of two active chromospheres. In this case detailed modeling and study of the stellar atmosphere is not possible and deductions are usually based on the temporal evolution of these lines. The present observations of TY Pyxidis have demonstrated that Ca II emission cores are present on both components of the system. Both stars therefore have very active chromospheres with significant non-radiative heating. The primary component is probably slightly more active than the secondary since the almost constant average velocity of the profiles are skewed slightly in favour of the primary. The apparent overall blue-shift in this emission could indicate the existence of bulk upflow of emitting plasma similar to that seen in the Hα excess emission observed on ER Vulpeculae.

Significant increases in the flux in the Ca II lines have been observed from TY Pyx which are approximately centred around the secondary eclipse and are probably associated with the primary component. This increase correlates well with a smaller increase in the Hβ excess which can be attributed to the primary component. Since independent normalization has been applied to all spectra and the flux increase may reasonably be attributed to the *eclipsing* star for these observations it cannot be due to continuum level variations. These observations show that a significant increase in non-radiative heating occurred in the chromosphere of the primary between phases 0.47 and 0.52. One possibility is that an individual active region has rotated in and out of view on the surface of the primary during the observations. Assuming the two stars are synchronously rotating and the region is a corotating surface feature of zero dimensions then the duration of the event implies a minimum latitude of $\sim 55°$. Since the feature will have a finite area the latitude may be much greater than this. No photometric or spectroscopic observations of TY Pyx to date have revealed the presence of a high-latitude active region near phase 0.5. Furthermore the flux increase of $\sim$28% should give a noticeable modulation of the velocity if it is due to a corotating surface feature. If however the enhancement is due to a global phenomenon then no velocity modulation may be expected. This feature may therefore be a short-lived or transient event, although the smooth variation of flux is not typical of the impulsive/decay signatures of stellar Ca II flares. Additional observations of this system are required to establish the transient nature of this event or otherwise and to further investigate its origin.

7. Conclusions

The primary aim of this study was to use spectroscopic data to detect signatures of extended material in the atmospheres of one or both components of GK Hydrae and TY Pyxidis. The technique used was spectral subtraction with spectra taken during eclipses when such material might be expected to show absorption of the continuum of the background star. Unfortunately due to scheduling constraints it was only possible to observe the secondary eclipses for these binaries. Since the secondary of GK Hya is known to be the more active (Oliver 1974) primary eclipse would have been a much better probe of the system environment. However, for TY Pyx it has been shown that the primary component is the more active star and therefore more likely to show evidence for extended material during the secondary eclipse.

The present study has clearly detected excess emission in the activity sensitive lines of Hα, Hβ, Mg I b and also probably Na I D for GK Hya. Also found was a marginal detection of He I D_3 absorption whose velocity and depth were not measurable with any certainty and therefore could not be safely identified with an individual component of the system. However, all the excess emission peaks were originating on the secondary. The results indicate that the primary component of GK Hya is not active enough to be detected with the present instrumentation and that the mechanism giving rise to the emission is a global phenomenon and not associated with transient or discrete regions of activity on the secondary. The observations have not shown the presence of discrete absorption features which could be associated with structures in the atmosphere of the primary component. The lack of significant He I D_3 absorption and the ratio of the Balmer line equivalent widths has been found to be consistent with the emission originating in prominence-like material seen off the limb of the secondary. The implication is that a substantial fraction of the atmosphere is filled with such structures. When viewed against the disk of the star these features may cause the *marginal* broad band of absorption surrounding the emission peaks. If this is so then the velocity of the prominence material reaches a maximum of 360 km s^{-1} in a vertical direction, both as up-flows and down-flows. These velocities are an order of magnitude greater than those observed for similar structures (quiescent prominences) seen on the Sun.

GK Hya does not appear to be as active as ER Vul which is believed to have a saturated atmosphere for the secondary. This is in agreement with the relatively low levels of radio emission (Drake, Simon & Linsky 1989) and X-ray luminosity (Dempsey et al. 1993). Overall the observations are in agreement with the theoretical predictions of extensive prominence-like material around the sub-giant components of RS CVn systems. However, additional observations are required in order to confirm the presence of extended regions surrounding the secondary component of GK Hya.

For TY Pyx the presence of discrete absorption features which could be associated with structures in the atmosphere of the primary component have not been found. A broad absorption band is evident centred on the Hβ excess emission line which may be analogous to similar features seen for GK Hydrae which were interpreted as prominences viewed against the disk of the star. However, this work has highlighted the difficulty with the spectral subtraction technique in the blue part of the spectrum where many photospheric line blends occur. The unsatisfactory cancellation of such lines casts doubts on the detailed structure in subtracted spectra. Hence it is possible that the absorption band surrounding Hβ is an artifact of the subtraction technique. The observation of a broad excess absorption component around the Ca II K line in the subtracted spectra may indicate that the photospheric/lower chromospheric temperature structure in the G5 components of TY Pyx are somewhat different to that in the comparison star. It is interesting that the synthetic spectrum for this order appears to match very well the observed spectrum other than around the Ca II K line itself. However, since a similar mismatch in the wings of the Ca II H line has not been found this further suggests that a physical mechanism is not responsible for the excess absorption. Before any further conclusions can be drawn regarding this system a radical reassessment of the subtraction technique in this part of the spectrum is required. However, based on the present analysis it is likely that no significant regions of extended material exist around the primary component of TY Pyx.

The present observations of TY Pyx have clearly detected excess emission in Hβ and the Ca II H and K lines. The majority of the Hβ excess and a larger proportion of the Ca II excess emission can be attributed to the primary component of the system. This is in agreement with Montes et al. (1995a) who found the primary more active than the secondary in Hα excess emission. Rough calculations of the volume of the plasma responsible for the Hβ excess indicate that very large structures must be involved if the physical conditions are typical of other similar stars. This suggests that prominence-like material is the more likely explanation but this cannot be further investigated with the present data.

A distinct distortion wave in the photometric light curve for GK Hya has not been found although intrinsic variability does appear to be present (Popper & Dumont 1977; Caton 1986). Neither have convincing wave-like distortions been found in the optical light curve of TY Pyx. Such distortion waves are normally attributed to the presence of star-spots and associated plages on the surface of the star. If the majority of the excess emission in these systems is due to large prominences covering the surface then no such phase variation of the photometry would be seen. This suggests minimal coverage by star-spots and associated plage regions for the sub-giant components of GK Hya and TY Pyx. However, photometry of the dwarf components of ER Vul (Menella 1990; Hill, Fisher & Holmgren 1990) suggest the predominance of star-spots and low-lying plage-like material. Dwarf stars have higher surface gravities and electron densities and so their emission regions may be different to those on sub-giant stars. It is possible that plage regions dominate the emission in dwarfs while prominences are more easily seen in sub-giants (Buzasi 1989). Another factor which may be important is the effect of Roche lobe filling. Some RS CVn stars are known to be close to filling their Roche surfaces (e.g. UX Ari and AR Mon). In such systems it is possible that large cool extended regions could form more easily in the corona than in other systems even though mass streaming is not taking place. Although no evidence has been found for discrete extended regions in any of our target stars, detailed analysis of the spectroscopic data shows broad agreement with the above scenario.

The existence of prominence-like material has been postulated in a number of active close binaries. Hall et al. (1990) reported the presence of an absorption feature near the secondary eclipse of the SS Boo system which they interpret as material extending at least one stellar radius above the active star's surface. Out of 10 systems studied by Hall & Ramsey (1992) eight seemed to show similar evidence of extended material. Other less direct methods have been used to demonstrate the occurrence of prominence-like features in RS CVns (Buzasi 1989). The results of this study to date have failed to show spectroscopic signatures which can unambiguously be associated with such structures. It is possible that large extended regions exist in these systems which were not conveniently positioned to be seen during the observations. On the basis of our observational data it is appropriate to conclude that extended matter is not a characteristic of RS CVns in general although prominence-like material probably exists in many.

Acknowledgements. Research at Armagh Observatory is grant aided by the Dept. of Education for N. Ireland. We also acknowledge the computer support by the STARLINK project funded by the UK PPARC. This research has, in part, made use of the Simbad database, operated at CDS, Strasbourg, France. AGG would like to thank Armagh Observatory for a research scholarship during the period of this work.

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