PHOTOSPHERIC ABUNDANCE PECULIARITIES IN COOL, CHROMOSPHERICALLY ACTIVE STARS

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Abstract

We report the determination from high-resolution optical spectra of the physical parameters and photospheric abundances of 14 single-lined chromospherically active binaries. The stars analyzed are generally found to exhibit peculiar abundance ratios compared to inactive, Galactic disk stars of similar metallicities (a phenomenon best illustrated in the case of oxygen). Although this behaviour may be attributable to large spot groups or NLTE effects arising from non-thermal excitation, more general shortcomings in our modelling of the atmospheres of K-type stars cannot be ruled out at this stage.

Key words: Stars: fundamental parameters – stars: abundances – stars: individual: RS CVn binaries

1. Introduction

Active binaries are defined as short-period binary stars with late-type components in which rotational locking significantly enhances magnetic activity and thus chromospheric and coronal emission. It is becoming increasingly clear that various issues related to this class of objects would greatly benefit from a detailed knowledge of their photospheric abundances. First, the recent availability of high-resolution spectrographs onboard various X-ray satellites has opened up the possibility of deriving the coronal abundances of several chemical species and investigating the chemical fractionation processes taking place between the photosphere and the corona (e.g., Drake 2003). Second, an accurate knowledge of their evolutionary status is necessary for modelling the dynamo processes resulting from the complex interplay between the spinning up of the stars and changes in their internal structure. In both cases, accurate photospheric abundances of elements other than iron are needed (e.g., the isochrone ages strongly depend on the abundance of the α elements adopted).

Unfortunately, these pieces of information are generally lacking. Because these objects are usually cool and fast rotators, any spectral analysis is plagued by severe blending problems. The few abundance studies performed to date thus often relied on the spectral synthesis of a limited spectral range, with only the iron content being determined (e.g., Randich et al. 1994). Not only these technical difficulties, but also the combined, hardly quantifiable action of various activity-related phenomena on the final results (e.g., cool stellar spots, prominent chromosphere) have arguably largely contributed to the slow progress in this field. In an effort to tackle these issues, here we present the results of a curve-of-growth abundance analysis of a sample of RS CVn binaries with slow rotation rates ($v \sin i \lesssim 10$ km s^{-1}).

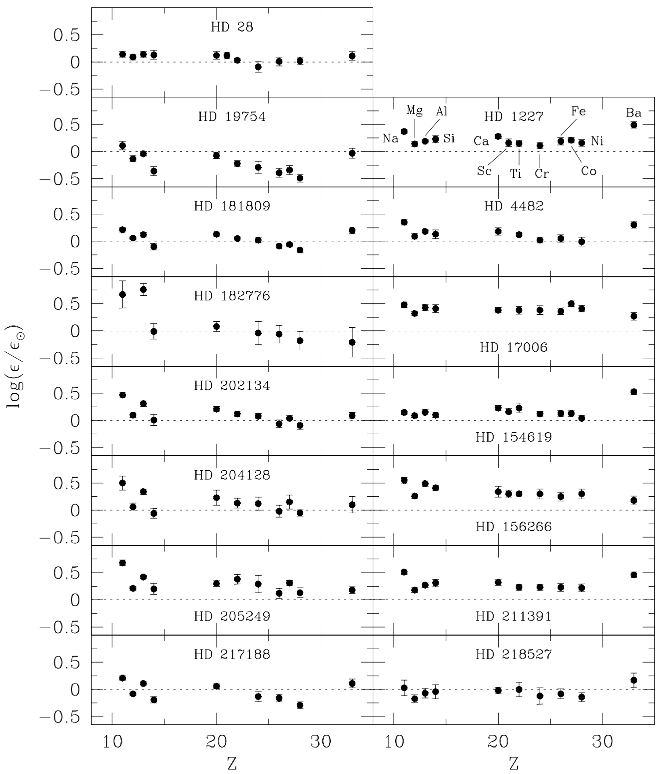

Figure 1. Abundance patterns for the active (left-hand panels) and control stars (right-hand panels). The chemical elements are identified in the right-hand, upper panel. The position of barium has been shifted for the sake of clarity to Z=33. From Morel et al. (2004).

2. Observations and analysis

Spectra of 14 single-lined active binaries (G8–K2 IV–III) taken from the catalogue of Strassmeier et al. (1993) were

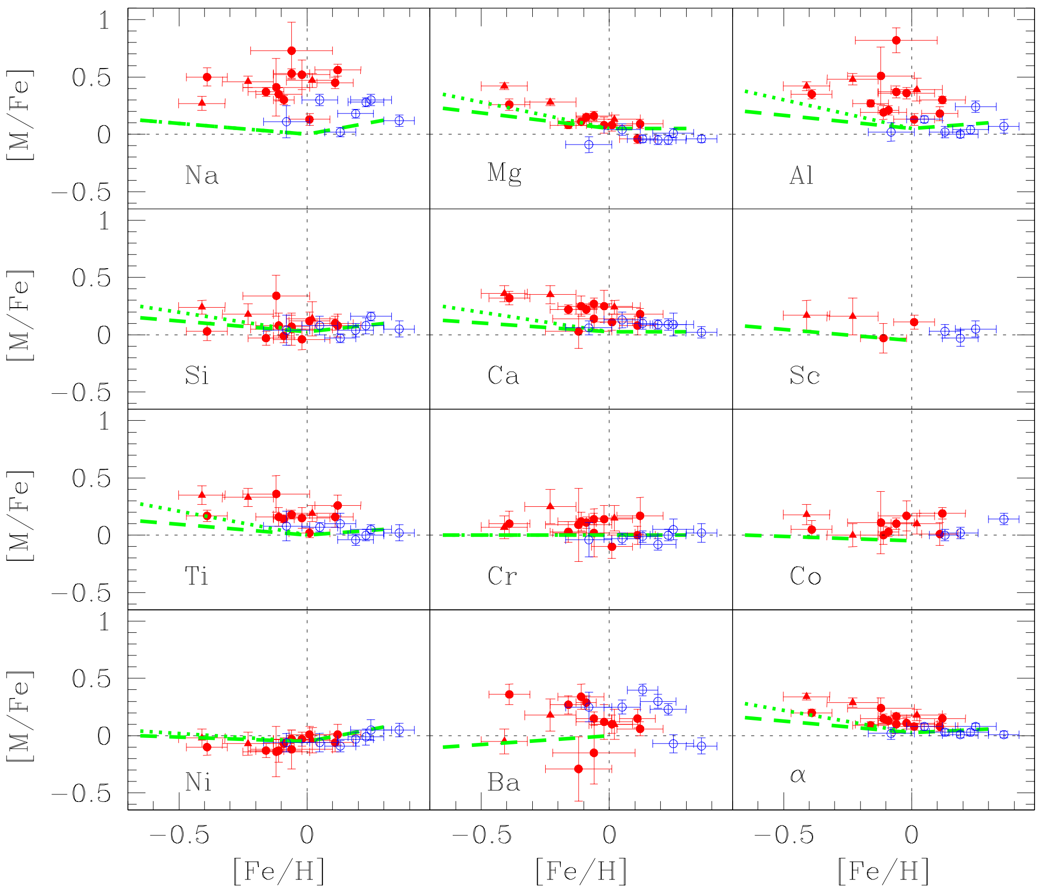

Figure 2. Abundance ratios as a function of [Fe/H] (Morel et al. 2004). The active binaries and stars in the control sample are indicated by filled and open circles, respectively (in the electronic version of the proceedings, red and blue circles refer to active and control stars, respectively). The possible thick disk stars are indicated by filled triangles. We define the mean abundance of the α-synthezised elements, [α/Fe], as the unweighted mean of the Mg, Si, Ca and Ti abundance ratios. The thick dashed and dotted lines show the characteristic trends of kinematically-selected samples of thin and thick disk stars, respectively (Bensby et al. 2003). The data for Sc, Co and Ba are taken from Reddy et al. (2003).

obtained at ESO in 2000 and 2003 using the echelle spectrograph FEROS (3600–9200 Å; resolving power R∼48 000). A control sample made up of 7 single stars of similar spectral type, but with a much lower level of X-ray emission (Hünsch et al. 1998) was also observed.

The abundances of 13 chemical species (among which lithium) were derived using the measured equivalent widths (EWs) of about 90 carefully-selected spectral lines, along with a set of 1-D line-blanketed LTE Kurucz atmospheric models, as input for the MOOG software. The oscillator strengths were calibrated with a very high signal-to-noise FEROS solar spectrum. The abundances of Na, Mg and Ca have been corrected for departures from LTE using literature data (see Morel et al. 2004).

The stellar effective temperatures and surface gravities were derived from the excitation and ionization equilibrium of the iron lines, while the microturbulent velocity was determined by requiring the Fe I abundances to be independent of the EWs.

3. Results and discussion

Figure 1 presents the abundance patterns of the active and control stars. The active binaries exhibit as a class a chemical composition departing more conspicuously from the solar mix (compare the left- and right-hand panels). As can be seen in Fig. 2, the active binaries do not follow the characteristic trends presented by inactive, FG dwarfs of the Galactic disk between the abundance ratios and [Fe/H] (e.g., Al). At a given metallicity, a significant overabundance is often observed in the active stars.

There is a rough, positive correlation between the abundance ratios of several elements and the activity level (Fig. 3). As discussed by Morel et al. (2004), this is unlikely to be an artefact of an increasingly incorrect determination of the atmospheric parameters at higher activity levels. There is considerable evidence for the existence of large spot groups in RS CVn binaries (e.g., O'Neal et al. 1996). The same abundance analysis carried out on synthetic, composite Kurucz spectra with a varying spot

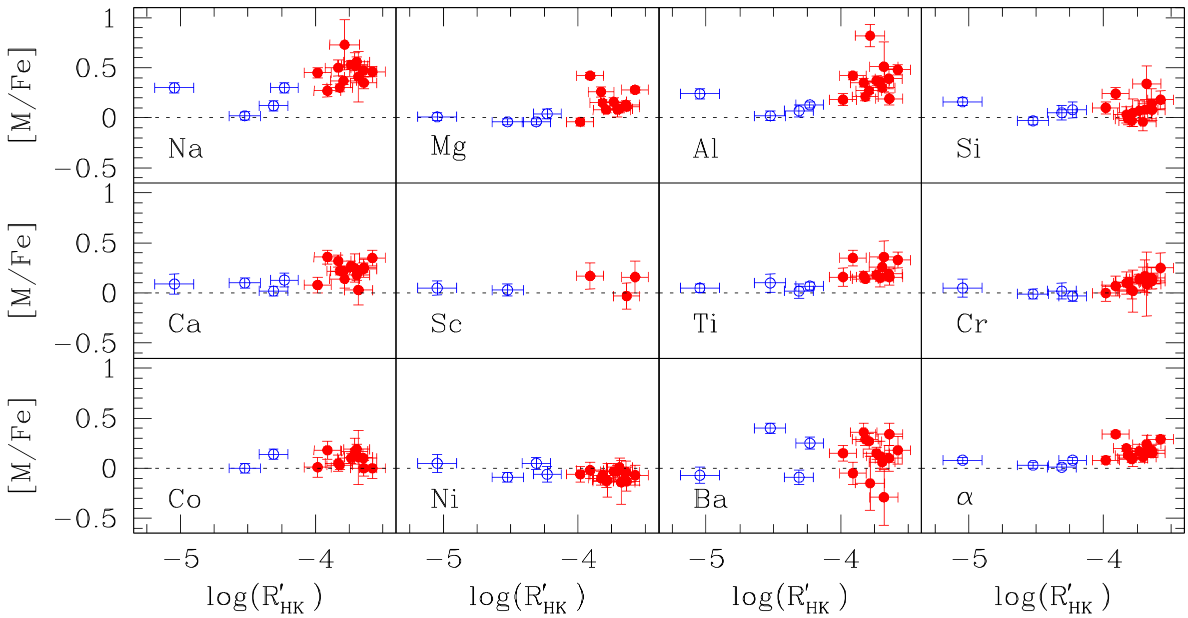

Figure 3. Abundance ratios as a function of the activity index $R'_{\rm HK}$ derived from the Ca II *H+K lines (Morel et al. 2004). Symbols as in Fig. 2. Similar trends between the abundance ratios and the activity level are also seen using an activity index, $R_{\rm X}$, derived from X-ray data.*

coverage shows that cool spots lead to a general overestimation of the abundance ratios, in qualitative agreement with the observations. In the case of oxygen, however, the distinct behaviour of the O I triplet and [O I] λ6300 likely diagnoses unexpectedly large NLTE effects affecting the permitted lines (Fig. 4). It is conceivable that a similar interpretation may apply to other elements.

Although we have interpreted above our results in terms of activity-related phenomena, we caution that the stars in our sample with the most peculiar abundance ratios are also often the coolest (see Fig. 5). Therefore, we cannot rule out the possibility that more general limitations in our understanding of K-type subgiants (e.g., inadequacies in the atmospheric models, NLTE line formation) also play a significant role.

4. Conclusion

The first results of our ongoing programme using high-resolution spectra to derive in a self-consistent way the photospheric parameters and abundances of a large sample of chromospherically active binaries clearly suggest peculiar abundance ratios compared to inactive, Galactic disk stars of similar metallicities. Large spot groups or NLTE effects arising from non-thermal line excitation may be responsible for this behaviour, but shortcomings in our atmospheric modelling of cool stars cannot be ruled out at this stage. Our forthcoming abundance analysis of a large sample of inactive, K-type stars will allow us to disentangle temperature from activity effects. Further developments of this project will also include the determination of the abundances in individual components of spectroscopic binaries.

Acknowledgements

This research was supported through a European Community Marie Curie Fellowship (No. HPMD-CT-2000-00013).

References

Bensby, T., Feltzing, S., & Lundström, I. 2003, A&A, 410, 527
Bensby, T., Feltzing, S., & Lundström, I. 2004, A&A, 415, 155
Drake, J. J. 2003, Advances in Space Research, Vol. 32(6), 945
García López, R. J., Rebolo, R., Herrero, A., & Beckman, J. E. 1993, ApJ, 412, 173
Hünsch, M., Schmitt, J. H. M. M., & Voges, W. 1998, A&AS, 127, 251
King, J. R., & Boesgaard, A. M. 1995, AJ, 109, 383
King, J. R., & Hiltgen, D. D. 1996, AJ, 112, 2650
King, J. R., Soderblom, D. R., Fischer, D., & Jones, B. F. 2000, ApJ, 533, 944
Morel, T., Micela, G., Favata, F., Katz, D., & Pillitteri, I. 2003, A&A, 412, 495
Morel, T., & Micela, G. 2004, A&A, 423, 677
Morel, T., Micela, G., Favata, F., & Katz, D. 2004, A&A, 426, 1007
O'Neal, D., Saar, S. H., & Neff, J. E. 1996, ApJ, 463, 766
Randich, S., Giampapa, M. S., & Pallavicini, R. 1994, A&A, 283, 893
Reddy, B. E., Tomkin, J., Lambert, D. L., & Allende Prieto, C. 2003, MNRAS, 340, 304
Schuler, S. C., King, J. R., Hobbs, L. M., & Pinsonneault, M. H. 2004, ApJ, 602, L117
Strassmeier, K. G., Hall, D. S., Fekel, F. C., & Scheck, M. 1993, A&AS, 100, 173

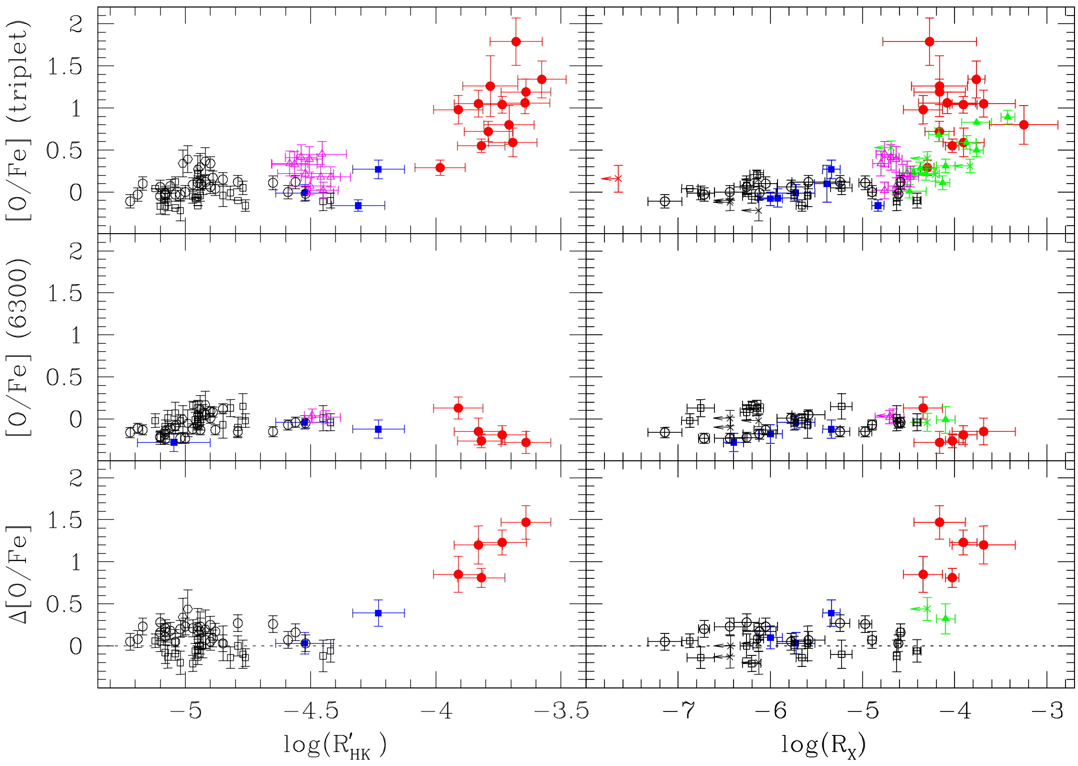

Figure 4. Oxygen abundances as a function of the activity indices $R'_{\rm HK}$ and $R_{\rm X}$ (Morel & Micela 2004). The bottom panels show the difference between [O/Fe] yielded by the O I triplet and the [O I] λ6300 line. Filled circles: RS CVn binaries (Morel et al. 2003, 2004), filled squares: field subgiants (Morel et al. 2004), filled triangles: Pleiades stars (King et al. 2000; Schuler et al. 2004), open triangles: Hyades stars (García López et al. 1993; King & Hiltgen 1996), open circles, squares and hexagons: disk dwarfs (from Bensby et al. 2004, King & Boesgaard 1995 and Reddy et al. 2003, respectively). The colour coding in the electronic version of the proceedings is the following: RS CVn binaries (red), field subgiants (blue), Pleiades stars (green), Hyades stars (magenta). The crosses in the right-hand panels are upper limits.

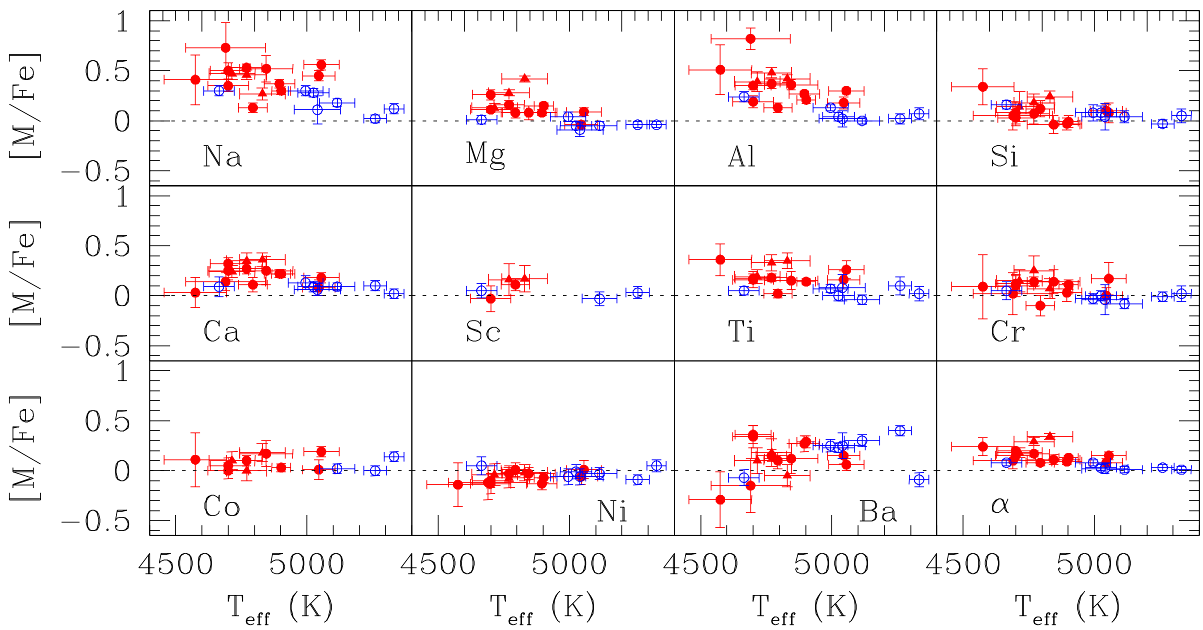

Figure 5. Abundance ratios as a function of the excitation temperatures (Morel et al. 2004). Symbols as in Fig. 2. A similar relationship is also observed between [O/Fe] (triplet) and T_{eff} (Morel & Micela 2004).