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Precise determination of stellar temperatures from spectroscopic data ⋆

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Abstract. We present a spectroscopic method based on line-depth ratios (LDRs) for the determination of photospheric temperatures in different types of stars. Although the method would require high spectroscopic resolution, our medium resolution (R = 14000) has been able to measure the modulation of the average surface temperature with sensitivity around 10 Kelvin degrees in two classes of variable stars, i.e. spotted active stars and Cepheid pulsating variables. By means of this analysis, it is possible to derive the fractional spotted area and the spot temperature in spotted stars for which simultaneous spectroscopic and photometric observations are available. For Cepheid stars, the analysis of our spectra allows us to measure simultaneously two fundamental parameters for the study of pulsation properties, namely temperature and radial velocity.

Key words. stars: activity - stars: variability - stars: individual: VY Ari, HD 166, δ Cep

1. Introduction

The determination of stellar temperature has a very important role in the study of stellar physics. Indeed, this physical parameter is fundamental for locating stars in the HR diagram, for abundance determination, for studies of gravity, and so on, but its measure is often not as accurate as it is needed. In this context, to find a very sensitive diagnostics of photospheric temperature is of paramount importance.

In the past, the strength of absorption lines has been used for spectral classification, given their dependence on gravity, pressure and temperature, but it is not directly useful for an accurate temperature calibration. The ratio of depth of two absorption lines (LDRs) with different excitation potential proves to be a very suitable temperature diagnostics, after an appropriate calibration has been done. It has been shown that the LDRs allow to derive temperature variations with sensitivity of only a few Kelvin degrees (Gray 1994).

We have explored the line-depth ratio method for accurate monitoring of temperature variations due to cool spots in magnetically active stars and during the pulsations of a variable star.

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2. Observations and reduction

Spectroscopic observations have been obtained from October 16th, 2000 to January 7th, 2001 for the active stars and in 2002 from July 7th to September 24th for δ Cep at the *M. G. Fracastoro* mountain station of Catania Astrophysical Observatory. The observations have been performed with the REOSC spectrograph at the 91-cm telescope. The ECHELLE spectra were recorded on a CCD camera equipped with a thinned back-illuminated SITe CCD of 1024×1024 pixels. The resolution was about 14 000.

The extraction of spectra from the CCD images was performed by using the ECHELLE task of the IRAF[1] package. Detailed informations on data reduction are given in Catalano et al. (2002).

3. Calibration of LDR

We have developed a calibration of line-depth ratios into temperature selecting about 20 line pairs whose depth was measured in spectra of standard stars of different spectral type and luminosity class. We have chosen pairs of absorption lines in which one line had no temperature dependence and the other one was very temperature-sensitive. Since the calibration relations of line-depth ratios into an absolute temperature scale are very often gravity dependent, we have corrected the gravity effect in order to take into account both main sequence and giant stars, following the calibration procedure described in Catalano et al. (2002).

For the studied targets, we have converted the individual line-depth ratios into temperature through the calibration relations derived from the standard stars.

For each line pair, the LDR analysis gives a temperature sensitivity of 10-20 K for a variation of 1% in the individual LDR.

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of the Universities for Research in Astronomy, inc. (AURA) under cooperative agreement with the National Science Foundation.

Table 1. RS CVn stars

Star	Sp. Type
λ And	G8III
HK Lac	K0III
HR 7275	K1IV
IM Peg	K2III-II
VY Ari	K3-4V-IV

4. Results

Rotational and pulsational modulations of surface temperature for three different types of star, namely slowly rotating RS CVn binaries, young solar-type single stars and classical Cepheids are currently studied by our group. In Tables 1 and 2 lists of studied RS CVn binaries and single active stars respectively are given. From the LDR-variations converted into temperature-variations by means of the calibration, we derive an average temperature variation by making a weighted mean of the values obtained from each useful LDR.

4.1. The active star VY Ari

Fig. 1 reports, as an example, the temperature variation of the single-lined active binary VY Ari (K3-4 V-IV, $P_{\rm rot}$ = $16\overset{\rm d}{.}1996$[2]). The amplitude of the temperature modulation is 156 K, which is the result of a inhomogeneous distribution of cool starspots. The VY Ari spectra have been acquired in time period of about four star rotation and this confirms that active binaries of RS CVn type have large spot coverage which can survive for several stellar rotations (Strassmeier & Bopp 1992).

4.2. The solar-like star HD 166

We are also studying the rotational modulation of temperature, derived from LDRs, in some young solar-type stars. They exhibit an intermediate activity level between the solar one and that typical of RS CVn binaries. Here we

[2] The rotational period is taken from Strassmeier et al. (1997)

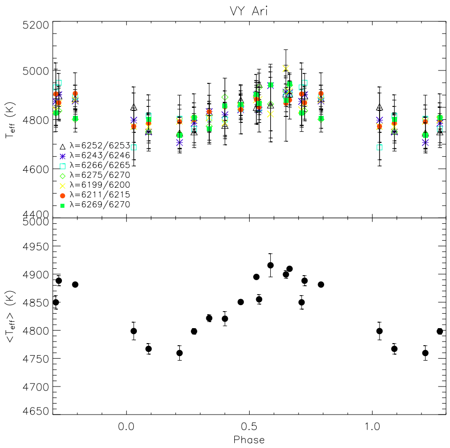

Fig. 1. Upper panel: temperature curves of VY Ari obtained from the individual LDRs. Different symbols have been used for the different LDRs. Lower panel: average effective temperature as a function of rotational phase.

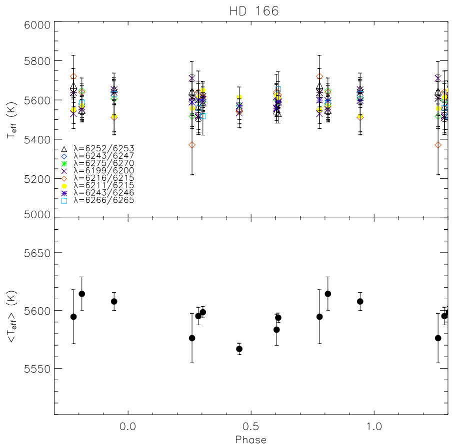

Fig. 2. Upper panel: temperature curves of HD 166 obtained from the individual LDRs. Lower panel: average effective temperature as a function of rotational phase.

Table 2. Young solar-type stars

Star	Sp. Type
χ1 Ori	G0V
κ1 Cet	G5V
HD 166	K0V
ϵ Eri	K2V

report the temperature behavior of the single main sequence star HD 166 (K0V, $P_{rot} = 6\overset{d}{.}23$ [3]). HD 166 shows a clear rotational modulation with an averaged temperature amplitude of only 48 K (Fig. 2).

4.3. *The Cepheid star δ Cep*

We have tested the LDR method on the classical Cepheid star δ Cep (F5Ib-G1Ib, $P_{puls} = 5\overset{d}{.}366341$ [4]). As shown in Fig. 3, from the same spectra we have obtained simultaneous informations on the amplitude of the average temperature curve (1369 K) and of the radial velocity curve (31 km/s). In Fig. 3 we also show other temperature measurements obtained by different authors, as well as the V light curve obtained by Barnes et al. (1997) and Kiss (1998). As we can see, the agreement between these $T_{\rm eff}$ data is very good. Moreover, the radial velocity curve of δ Cep is almost a mirror image of the light curve. The luminosity maximum corresponds to the highest velocity of recession and the two curves are slightly shifted, as it is predicted by the pulsation theory (Kukarkin 1975).

5. Conclusions

A spectroscopic monitoring of magnetically active and pulsating stars has allowed us to detect modulations of the photospheric temperature. In the first class of stars the temperature modulation is due to the presence of dark cool spots, while in Cepheid stars the variation of temperature is tied to its radial pulsation.

For the active stars, a combined analysis of contemporaneous temperature and light curves permits to obtain a unique solution for the spot temperature and spot coverage factor (Frasca

[3] The rotational period is taken from Gaidos et al. (2000)

[4] We have used the period and the epoch of brightest V given by Moffett (1985).

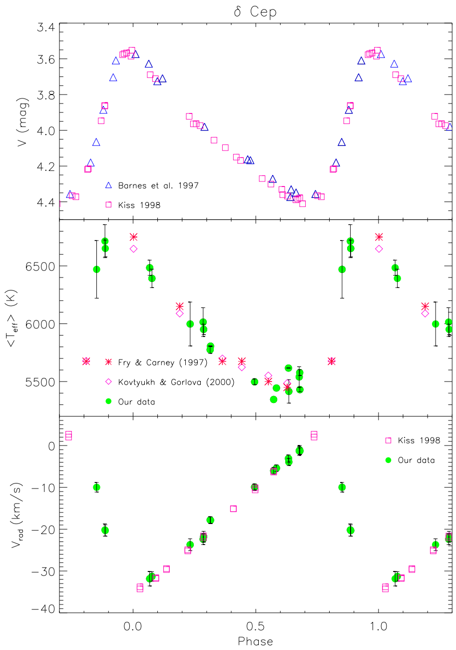

Fig. 3. Upper panel: light curves achieved by other authors. Middle panel: average effective temperature as a function of pulsational phase obtained by us, Fry (1997) and Kovtyukh & Gorlova (2000). Lower panel: radial velocity curves from observations performed by us and Kiss (1998).

et al. 2004). Spot temperatures we derive in this preliminary study are closer to that typically measured in solar spot penumbrae rather than in sunspot umbrae, probably due to the larger size of penumbra and therefore the larger weight in determining the spectral line depths.

For the analysed Cepheid star we have shown that we can simultaneously record two fundamental parameters, namely temperature and radial velocity. From these data and light curve it is possible to derive accurate values of Cepheid absolute magnitudes which are of fundamental importance for distance determinations.

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References

Barnes, T. G., Fernley, J. A., Frueh, M. L., Navas, J. G., Moffett T. J. & Skillen I. 1997, PASP, 109, 645

Catalano, S., Biazzo, K., Frasca, A. & Marilli, E. 2002, A&A, 394, 1009

Frasca, A., Biazzo, K., Catalano, S., Marilli, E., Messina, S. & Rodonò, M. 2004, A&A, submitted

Fry, A. M., & Carney, B. W. 1997, AJ, 113, 1073

Gaidos, E. J., Henry, G. W., & Henry, S. M. 2000, ApJ, 120, 1006

Gray, D. F. 1994, PASP, 106, 1248

Kiss, L. L. 1998, MNRAS, 297, 825

Kovtyukh, V. V., & Gorlova, N. I. 2000, A&A, 358, 587

Kukarkin, B. V. 1975, *Pulsating Stars*, Halsted Press, p. 8

Moffett, T. J., & Barnes, T. G. 1985, ApJS, 58, 843

Strassmeier, K. G. & Bopp, B. W. 1992, A&A, 259, 183

Strassmeier, K. G., Bartus, J., Cutispoto, G., & Rodonò, M. 1997, A&AS, 125, 11