THE EFFECTIVE TEMPERATURES OF K-GIANTS

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ABSTRACT. The spectral classification of stars based on the ratios of the line depth, which are sensible to the temperature changes. Such calibrations were used for various stars (Gray, 1994; Kovtyukh et at., 1998). From the high- resolution spectra of K-giants, we selected 15 pairs of atomic lines and we derived 15 analytical relations for the determination of effective temperature T_{eff}. Our calibrations were constructed for 5000 K < T_{eff} < 4000 K and for [Fe/H] from 0 to -1 dex. The abundance dependence is taken from the synthetic spectral calculations by the Kurucz's (1993) models. We determine T_{eff} for Arcturus on the high resolution high dispersion spectra obtained at different times.

Key words: Stars: K-giants: temperature; stars: Arcturus.

1. Introduction

At present the high-dispersion CCD stellar spectra can be obtained with high (100 or more) signal-to-noise (S/N) ratios over a wide wavelength range. Thus, high-accuracy eguivalent widths can be used to analyze the chemical composition and other parameters of the stars. The observed spectra are well described by the methods developed to compute synthetic spectra, suggesting that the theoretical models in use today adequately represent real objects. Recently, fairly reliable sets of oscillator strengths have also appeared. Now, we can reach a qualitatively new level of reliability in analysing the chemical composition of the stars and K-giants, in particular. At the same time there is a problem of the definition of the reliable effective temperatures (T_{eff}). The existing methods of determining T_{eff} are based on the B-V and R-I colour indices of Johnson‘s system and other photometric systems; on a comparison of observed and synthetic Balmer-line profiles; on the condition of Boltzmann‘s equilibrium for FeI lines; and on spectrophotometric data. Recently, the method of infrared fluxes, which yields good results for some objects, has been developed. Since all these calibrations give errors up to 200-300 K, and the estimates obtained by different methods are commonly in disagreement with one another. In particular, the colour indices are very sensitive to the surface gravity $\log g$ and to the turbulent velocity V_t. Large errors are due to interstellar reddening; this allowance cannot always be made properly, especially for unique objects. The hydrogen- line profiles are affected by metallicity and by $\log g$ (for [Fe/H] = 0). A spectrophotometric analysis is possible only for sufficiently bright objects, the same is also true for the method of infrared fluxes. As a result, the temperature determination is ambiguous. At that, the knowledge of the precise temperatures is needed for abundance determination, and as well for locating stars in the H-R diagram, for studies of gravity and mass, and so on. Accordingly, determining reliable effective temperatures T_{eff}, in particular, for K-giants, becomes a problem of current importance. Uncertainties in T_{eff} are currently the main source of uncertainties in the chemical composition of K-giants. However, T_{eff} cannot be determined by using the existing methods with an accuracy higher than 150-200 K, which prompts us to search for new approaches to determine the temperatures.

One of them appears to have surfaced in recent years. Sasselov & Lester (1990) showed that the relative temperatures T_{eff} could be determined, in principle, with an accuracy of ± 30 K from the ratio of CI and SiI lines with widely differing excitation potentials in infrared region of the spectrum. Such calibrations, for the equivalent widths, have long been used for B stars (Kopylov, 1958). Gray (1989) have used the ratio of line depths for two spectral lines to determine stellar temperatures with a high precision for giants. Gray & Johanson (1991), Gray (1994) substantiated the validity of this technique for F-G dwarfs in visible region and noted that the relative temperatures could be determined by this method with high accuracy. Kovtyukh et al. (1998) carried out the determination of T_{eff} for F-G supergiants with an accuracy higher then 50-80 K from spectroscopic criteria. Our aim is to derive analytical relations for determining high-accuracy temperature from spectroscopic criteria in visible spectral range (5000-6700 Å) for K-giants.

2. The observations

To estimate the temperature scale, we used the high-dispersion spectra of K-giants (S/N > 100), obtained with an echelle spectrometer (Musaev, 1993) on the 1-m Special Astrophysical Observatory telescope and

Table 1. Parameters of the spectral lines used to determine T_{eff}

λ, Å	El.	EPL.	λ	El.	EPL.
6495.78	FeI	4.83	6498.95	FeI	0.95
6419.98	FeI	4.73	6349.48	VI	1.85
6378.26	NiI	4.15	6336.1	TiI	1.44
6244.47	SiI	5.61	6233.2	VI	0.27
6175.42	NiI	4.08	6177.26	NiI	1.82
6155.69	SiI	5.61	6224.51	VI	0.28
6106.6	SiI	5.61	6126.22	TiI	1.06
6086.29	NiI	4.26	6092.81	TiI	1.88
5805.23	NiI	4.16	5798.51	CrI	1.03
5772.14	SiI	5.08	5798.51	CrI	1.03
5666.68	SiI	5.61	5668.36	VI	1.08
5655.18	FeI	5.06	5668.36	VI	1.08
5646.61	SiI	4.93	5570.43	MoI	1.33
5398.29	FeI	4.44	5388.35	NiI	1.92
5398.29	FeI	4.44	5392.07	ScI	1.92

Table 2. Polynomial coefficients of the R-T_{eff} calibrations

a_0	a_1	a_2
2382.09	+ 4537.8	- 1770.5
3640.33	+ 359.627	- 23.3282
1575.00	+ 5920.31	- 2705.15
3090.39	+ 3162.83	- 1376.94
1047.75	+ 4233.5	- 798.029
2977.65	+ 12113.5	- 20551.7
3388.56	+ 5244.77	- 3764.43
2946.93	+ 1647.65	- 345.399
3657.57	+ 634.718	- 68.7818
3605.03	+ 748.523	- 105.681
3067.52	+ 3671.43	- 1835.13
2809.85	+ 2316.02	- 541.581
2769.62	+ 2252.7	- 604.371
585.114	+ 5081.71	- 1589.99
3357.59	+ 594.637	- 52.4096

on 1.52-m Haute Provence Observatory telescope (Soubiran et al., 1998). The mean spectral resolution is R=36,000 and 40,000, spectral range 4400-6800 and 4800-6700Å respectively. The spectral reduction was carried out by DECH20 code (Galazutdinov, 1992).

3. The method of temperature determination

To derive analytical relations for determining temperature T_{eff} from spectroscopic criteria we used the visible spectral range 5000-6700 Å . In the range, we studied all unblended Si, Ti, V, Cr, Fe, and Ni lines to check if they are suitable for decision of our task. Sheminova (1993) has shown, that weak metal lines with low excitation potentials are most sensitive to the temperature. We selected pairs of lines that satisfied the following criteria: 1) the excitation potentials of the lines must differ as much as possible; 2) the lines must be close, if possible, to eliminate errors in continuum placement; 3) since ionic lines are quite sensitive to $\log g$, they were excluded from the analysis; 4) we also chose pairs of lines of the same element (occasionally, widely separated) to eliminate a possible dependence of the temperature on abundance (in the case of highly anomalous chemical composition); 5) the lines must be weak enough to eliminate a possible dependence on V_t; 6) a spectral region with a large number of telluric lines was excluded from the analysis.

We chose 15 pairs from all the studied combinations of lines, which were sufficiently sensitive to variations in T_{eff} and have a low scattering of the derived temperatures. Tab. 1 gives the main parameters of our lines: wavelengths (λ), chemical elements, excitation potentials of the lower level (EPL.). The derived calibrations are given in tab. 2.The depth ratios R1 / R2 of the corresponding lines are denoted by R.

To calibrate temperature scale, we used K-giants with well-studied temperatures (Mishenina & Tsymbal, 1997; Haute Provence). Using sufficiently large number of criteria, we can determine T_{eff} by our method with an error no more than ± 50-80 K (depending on the number of used criteria, and the quality of spectra). As soon as high-precision temperatures T_{eff} will be available for giants, we will be able to convert our calibrations to the new scale by applying an additive correction to all relations.

4.The effective temperature of Arcturus

Arcturus (α Boo), Sp K1.5 III (Keenan & McNeil, 1989), is one of the brightest well studied late-type stars. Arcturus has well-determined parallax 0".092 ± 0".005 (Woolley et al.,1970) corresponding to distance of 10.8 ± 0.6 pc. Most of studies of Arcturus have included a determination of stellar effective temperature T_{eff}, a parameter whose accuracy is pivotal in meaningful derivations of chemical abundance and stellar mass. A well-studied star like Arcturus ought by now to be well enough modeled that it can constitute a reliable standard for assessing the quality of the different methods in use (spectral line analysis, classical model atmospheres), and for calculating systematic and random errors, both general to each method and specific to other stars.

Instead, the values of T_{eff} for Arcturus published to date cover a disconcertingly large range (Griffin, 1996), with evident consequences for determinations of the stars mass and the precise pattern of its chemical abundances (Trimble & Bell, 1981). A new value given by Dyck et al. (1996) has increased that range quite dramatically, and was in fact what drove us to examine this issue afresh, with a view to establishing the limits of T_{eff} that are achieved by combining classical models with the best available observational and

Table 3. Effective temperatures of α Boo

source	T_{eff}
this paper (1980)	4467
this paper (1993)	4424
this paper (1998)	4341
Martin(1977)	4300
Johnson et al.(1977)	4250
Blackwell & Shallis(1977)	4400
Blackwell et al.(1975)	4500
Mackle et al.(1975)	4260
Van Paraijs(1974)	4350
Gustafsson et al.(1974)	4030
Griffin & Lynas-Gray(1999)	4290

laboratory data. It has been known for over 30 years (Griffin, 1967) that Arcturus is a mildly metal-poor giants, its weak CN and CH, relative overabundance of light elements, and high space velocity earning it the designation "mild Population II". The atmospheric parameters derived by Peterson et al. (1993) from a thorough classical model-atmosphere analyses appear to represent the consensus of the results from modern spectroscopic analyses, so it was important to discover why the new program of Dyck et al.(1996) to measure the angular diameter of Arcturus and of other cool giants at infrared wavelengths should have produced a value of T_{eff} for Arcturus that was some 300K higher than that consensus.

We determined T_{eff} by our method for Arcturus on the high resolution high dispersion spectra obtained at different times. The R-T_{eff} calibrations were derived for solar metallicity and for Arcturus ([Fe/H] = -0.7) the abundance dependence was taken from the synthetic spectral calculations by the Kurucz's (1993) models. The calculation was made with the code STARSP (Tsymbal, 1994). The photographic spectrum of Arcturus (1980) was obtained on the first camera of 6m Special Astrophysical Observatory telescope by Panchuk V.E. in 1980. The CCD spectrum of Arcturus (1993) was obtained on the 1m Special Astrophysical Observatory telescope and the CCD spectrum of Arcturus (1998) was made on 1.52-m Haute Provence Observatory telescope. The temperatures of Arcturus determined by our method and other researcher are given in tab.3.

5. Conclusion

We selected 15 pairs of atomic lines and we derived 15 analytical relations for the determination of effective temperature T_{eff} on the high-resolution spectra of K-giants. The obtained R - T_{eff} relations make it possible to determine T_{eff} for K-giants with an accuracy higher than 100 K from the spectrum itself.

The derived temperatures of Arcturus on spectra, obtained at different times, are agree within the errors of determination.

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