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SPECTRAL LINE-DEPTH RATIO AS A PRECISE EFFECTIVE TEMPERATURE AND SURFACE GRAVITY INDICATOR FOR WARM STARS

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ABSTRACT

In order to determine the precise effective temperature and surface gravity of warm stars, all synthetic spectral lines in the wavelength range of 4000-5700Åwith T=6000–7750 K, and log g=3.5, 4.0, and 4.5 for [M/H]=0.0, V_{rot}=10 km s^{-1}, and V_{tubl}=2 km s^{-1} were calculated using the SYNSPEC package (Hubeny, et al., 1995) and the Kurucz (1995) model. Then, the depth-ratios for all line pairs were investigated and we selected two and six depth-ratios appropriate for the surface gravity and temperature indicators, respectively. We plotted six grids with X- and Y-axes for the depth-ratios of surface gravity and temperature, respectively, for the simultaneous estimation of these two atmospheric parameters. This method was applied to the spectum of δ Scu for the determination of its temperature and surface gravity simultaneously.

Key words : stars:temperature-stars:surface gravity-stars:atmosphere

I. INTRODUCTION

Effective temperature, as one of the basic stellar parameters, is important in stellar astronomy because it determines the location of stars on H–R diagram. Also, as the most important atmospheric parameter, it is used to determine the abundance and surface gravity. For pulsating variables, it is used to determine the pulsation constant and oscillation mode as well as radius with the so-called surface brightness method. Without precise temperatures, other physical and atmospheric parameters can hardly be estimated. Therefore, enormous efforts have been focused on determining as precisely as possible, the temperature for many years, and numerous methods have been developed for its determination (see Kovtyukh & Gorlova 2000). The color photometry is the simplest method, where the wide and intermediate band colors, such as (B–V), (b–y), (V–K) etc were calibrated as temperature sensitive indicators. Conversely, the slope of Paschen Continuum is also used. Balmer jump and wings of modest-strength lines, such as $H\alpha$ are used for hot and cool stars respectively. Each method has its own advantage and disadvantage, but the errors range from a few tens to a hundreds degree.

Thus, to determine a more precise temperature, a method was proposed by Gray (1989) where the line-depth ratio was used. In this method, the ratio of the depths of two lines having different sensitivity to temperature was employed. This technique was used for giant stars, where errors were about ± 20 K. Sasselov & Lester (1990) found that the ratio of CI and SiI lines may serve as a good thermometer for Cepheids providing a 30K precision. Gray & Johanson (1991) showed that 6251.83 VI and 6252.57 FeI line pairs are good temperature indicators for late type F, G stars, and early type dwarfs with a precision of about 10K. Gray (1994) determined temperature of 65 G and K supergiants using 6252 VI and 6253 FeI lines. The metallicity effect was calibrated and it was reported that the temperature difference was about 50K from the results where the (B–V) and (R–I) colors were used.

Kovtyukh & Gorlova (2000) offered thirty- two functional formulas to determine the temperature from line-depth ratios for Cepheids and F-G supergiants. Gray & Brown (2001) calibrated five line-depth ratios for giant stars in the G3 to K3 spectral type range and detected temperature variations of 4 K. The advantage of this method is that a blending effect is smaller than the case of using the equivalent width with relatively free from uncertain contribution caused by uncertain line wing, small effects from different rotation, turbulence line broadening, and abundance, and small influence from spectral resolution. Thus, this method is appropriate for the investigation of temperature variation due to the rotation and non-homogeneous surface, of the cyclic temperature change for variable stars, and precise temperature structure of photosphere etc.

The main purpose of this paper is to identify spectral line pairs whose line depth-ratios are sensitive to the variation of temperature and surface gravity. Then, the grid produced by taking temperature and surface gravity ratios as a X- and Y-axes, which can be used to precisely determine temperature and surface gravity simultaneously. This is very similar to the case of determining the temperature and surface gravity at the same time on a (b–y)–m_1 grids using uvbyβ photometric data.

II. DISCUSSION

Using the Kurucz model and the SYNSPEC package, synthetic spectra were produced for the wavelength region of 4000–5700Å. The range of input atmospheric parameter values was 6000–7750K for temperature, and 3.5, 4.0, and 4.5 for surface gravity as well as metallicity, [M/H]=0.0 and turbulent velocity V_{tubl}=2 km s^{-1}, rotational velocity V_{rot}=10 km s^{-1}, and resolution of 0.01Å. The total number of produced lines was over a few tenths of a thousand. Then, only strong lines of about 2000 numbers with < 0.95 were selected. Among these, wavelengths corresponding to seven different temperatures and three different surface gravity values should coincide to produce a grid, and this depends on the value of spacing and fwhm of each line.

Then, 386 lines were selected for the wavelength accuracy within 0.03Å, and, for all possible combinations of arbitrary pairs under the condition of minimum 100Å difference of wavelength to minimize the effect of blending, depth ratios were calculated for three surface gravity values of 3.5, 4.0, and 4.5, as well as for eight temperature values of 6000, 6250, 6500, 6750, 7000, 7250, 7500, and 7750K. Next, only those pairs where depth ratios varied smoothly along different temperatures and surface gravities were selected. Also, for each pair, smoothed three curves corresponding to three different surface gravity values produced by the connection of the depth ratio values for eight different temperature values should not cross from one to the other.

We investigated all possible combinations of the pairs for log g and temperature, and it was found that (4101.733 Fe I, 4053.853 Ti II) and (4314.111 Sc II, 4252.624 Cr II) are appropriate for surface gravity indicators, and (4045.797 Fe I, 4000.451 Fe I), (4045.797 Fe I, 4003.769 Fe I), (4045.797 Fe I, 4007.265 Fe I), (4045.797 Fe I, 4027.659 Ni I), (4045.797 Fe I, 4053.853 Ti II), and (4045.797 Fe I, 4059.705 Fe I) are good for effective temperature estimation.

Finally, among all 12 combinations of two and six indicator pairs, six indicator pairs were selected to produce grids on the plane of the temperature and surface gravity axis in order to increase accuracy. In these six indicator pairs, the differences of ratio values were, for a given surface gravity value, relatively large for minimum and maximum temperatures of 6000K and 7750K. In Table 1, we present the depth-ratio values for six indicator pairs. As an example, Figure 1 shows a grid in the case of depth-ratio of (4045.797 Fe I/4007.265 Fe I) for surface gravity and temperature, respectively.

Thus, in the case of [M/H]=0.0, V_{rot}=10 km s^{-1}, and V_{tubl}=2 km s^{-1}, if we measure the line depth of above spectral lines, and calculate their ratios, temperature and surface gravity can be easily and precisely estimated using a corresponding grid, simultaneously. Because the line depth-ratios are independent of rotational and macroturbulence broadening, since both lines are reshaped in the same way, our grids are useful for other values above V_{rot}=10 km s^{-1}, and V_{tubl}=2 km s^{-1}. These two values were used only for the calculation of the synthetic lines from the Kurucz model. However, we would like to point out that the accuracy worsens as temperature increased because the interval between two neighboring grid points are reduced as temperature increases.

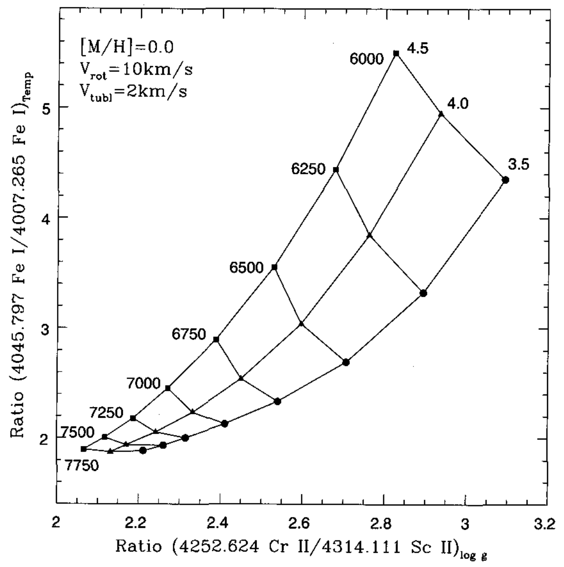

Fig. 1.— A grid of spectral line-depth ratio for the determination of eective temperature and surface gravity simultaneously.

III. CONCLUSION

We attempted to develop a simple method to determine temperature and surface gravity simultaneously using the line-depth ratios. In similar previous methods, only temperature can be determined. Also, in some cases, metallicity and/or surface gravity effect were calibrated, however, in any kind of calibration process, systematic error can be introduced inevitably. We believe that it is much better to use temperature and surface gravity grids corresponding to different metallicity, rotation velocity, and microturbulence than introducing calibration procedures. In the next paper, we try to apply our method to certain relatively long-period dwarf cepheids to determine their radii with the surface brightness method through spectroscopic observation with high resolution. Also, other grids can be used for different metallicity. Our method is necessary to extend to lower temperature stars too. We also try to compare the temperature and gravity values determined using our method with those from

TABLE 1.
LINE-DEPTH RATIOS FOR THE SIX PAIRS.

Te	(4314.111 Sc II, 4252.624 Cr II)			(4045.797 Fe I, 4000.451 Fe I)		
	log g			log g		
	3.50	4.00	4.50	3.50	4.0	4.50
6000	3.09	2.93	2.82	4.19	4.75	5.28
6250	2.89	2.76	2.67	3.21	3.71	4.28
6500	2.70	2.59	2.52	2.60	2.93	3.43
6750	2.54	2.45	2.38	2.25	2.45	2.80
7000	2.41	2.33	2.27	2.04	2.15	2.36
7250	2.31	2.24	2.18	1.92	1.97	2.09
7500	2.26	2.17	2.11	1.85	1.85	1.92
7750	2.21	2.13	2.06	1.80	1.79	1.81

	(4314.111 Sc II, 4252.624 Cr II)			(4045.797 Fe I, 4003.769 Fe I)		
6000	3.09	2.93	2.82	4.31	4.89	5.43
6250	2.89	2.76	2.67	3.28	3.80	4.39
6500	2.70	2.59	2.52	2.65	2.99	3.50
6750	2.54	2.45	2.38	2.28	2.48	2.84
7000	2.41	2.33	2.27	2.07	2.18	2.39
7250	2.31	2.24	2.18	1.94	1.99	2.12
7500	2.26	2.17	2.11	1.87	1.87	1.94
7750	2.21	2.13	2.06	1.81	1.80	1.83

	(4314.111 Sc II, 4252.624 Cr II)			(4045.797 Fe I, 4007.265 Fe I)		
6000	3.09	2.93	2.82	4.35	4.94	5.50
6250	2.89	2.76	2.67	3.32	3.84	4.44
6500	2.70	2.59	2.52	2.69	3.03	3.55
6750	2.54	2.45	2.38	2.33	2.53	2.89
7000	2.41	2.33	2.27	2.12	2.23	2.45
7250	2.31	2.24	2.18	2.00	2.05	2.17
7500	2.26	2.17	2.11	1.93	1.93	2.00
7750	2.21	2.13	2.06	1.88	1.87	1.89

	(4314.111 Sc II, 4252.624 Cr II)			(4045.797 Fe I, 4027.659 Ni I)		
6000	3.09	2.93	2.82	4.90	5.59	6.23
6250	2.89	2.76	2.67	3.70	4.28	4.96
6500	2.70	2.59	2.52	2.97	3.35	3.92
6750	2.54	2.45	2.38	2.55	2.77	3.16
7000	2.41	2.33	2.27	2.30	2.42	2.66
7250	2.31	2.24	2.18	2.15	2.20	2.34
7500	2.26	2.17	2.11	2.06	2.06	2.13
7750	2.21	2.13	2.06	2.00	1.98	2.01

	(4314.111 Sc II, 4252.624 Cr II)			(4045.797 Fe I, 4053.853 Ti II)		
6000	3.09	2.93	2.82	4.32	5.22	6.16
6250	2.89	2.76	2.67	3.18	3.90	4.78
6500	2.70	2.59	2.52	2.50	2.99	3.69
6750	2.54	2.45	2.38	2.12	2.43	2.93
7000	2.41	2.33	2.27	1.89	2.10	2.43
7250	2.31	2.24	2.18	1.75	1.90	2.12
7500	2.26	2.17	2.11	1.67	1.77	1.93
7750	2.21	2.13	2.06	1.61	1.70	1.81

	(4314.111 Sc II, 4252.624 Cr II)			(4045.797 Fe I, 4059.705 Fe I)		
6000	3.09	2.93	2.82	4.68	5.32	5.91
6250	2.89	2.76	2.67	3.56	4.11	4.76
6500	2.70	2.59	2.52	2.87	3.24	3.79
6750	2.54	2.45	2.38	2.48	2.70	3.07
7000	2.41	2.33	2.27	2.25	2.36	2.59
7250	2.31	2.24	2.18	2.10	2.16	2.29
7500	2.26	2.17	2.11	2.02	2.02	2.10
7750	2.21	2.13	2.06	1.96	1.95	1.97

color photometry, especially for (b–y)– c_1 or (b–y)–m_1 grids in the uvbyβ color system, which have been most widely used to determine the atmospheric parameters of high amplitude delta Scuti stars.

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