Spectroscopic Analysis of HIP 3026 and HIP 99938

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Abstract

The optical spectra of two stars HIP 3026 and HIP 99938 taken from the McDonald Observatory were analyzed for chemical abundances and temperature, mainly using the lines of FeI, FeII, MgI, MgII and NiI. The Image Reduction and Analysis Facility (IRAF) was used to analyse the spectral images. This report discusses the theory and procedure used to determine temperature from spectra.

1 Introduction

Spectroscopy is a major source of astronomical information. Spectroscopic methods allow experimenters to accurately determine the chemical composition, temperatures, atmospheric pressure and other parameters of observed objects. High resolution spectroscopy is a recent field which developed with the advent of improved instruments. It allows accurate determination of the line profiles. From the theory point of view, the Boltzmann equation and the Saha equation provide sufficient relations to determine temperature and abundances. However the errors involved are large. More advanced theory involving solving the radiative transfer equations and employing model stellar atmospheres is the currently prefered to measure parameters of stellar atmospheres. However this is only briefly discussed in this report.

2 Continuum and Doppler Correction

The spectrum obtained from the photosphere of stars usually consists of many absorbtion features superimposed over a continuum which can be approximated by a blackbody curve. Because the strength of the absorbtion feature is measured with respect to the continuum level in its neighbourhood, it is a standard practice to normalize the spectrum to unity with the continuum emission. A sixth order Legendre polynomial was fitted to the continuum with the IRAF tool `continuum`.

2.1 Multiplets

Multiplets are sets of lines created by transitions between two terms each consisting of multiple energy levels. The multiplets are useful for identification due to the fact that the relative line strengths as well as the relative separation between the lines remains constant even after Doppler shifts due to relative motion of the source and observer.

For measurement of the Doppler shifts of the stars, the OI, NaI and CaI multiplets at $7774\mathring{A}$, $5893\mathring{A}$ and $6099\mathring{A}$ were used. An example of the velocity correction is given in Table 2.1. The tool `dopcor` was used to correct the spectrum for the doppler shifts.

Table 1: Radial velocity calculations for HIP 99938

λ_{line} Å	λ_{lab} Å	Eq. Width Å	Geocentric Vel. kms^{-1}	Species
7768.901	7771.954	0.07378	-117.7653	OI
7771.117	7774.177	0.06033	-118.0015	OI
7772.345	7775.395	0.04943	-117.5975	OI
5887.656	5889.973	0.3477	-117.9325	NaI
5893.623	5895.940	0.1481	-117.8131	NaI
6159.763	6162.180	0.16	-117.5880	CaI
6100.336	6102.727	0.1036	-117.4563	CaI
5855.162	5857.459	0.09863	-117.5635	CaI
5526.241	5528.418	0.1815	-118.0533	MgI
5181.572	5183.619	0.8149	-118.3874	MgI
5170.654	5172.698	0.6217	-118.4635	MgI
4701.144	4703.003	0.204	-118.5018	MgI
5444.777	5446.924	0.1421	-118.1684	FeI
5391.051	5393.176	0.09364	-118.123	FeI
4889.569	4891.502	0.16	-118.4705	FeI
4888.832	4890.763	0.1342	-118.3658	FeI

To convert from the observed velocity to the heliocentric velocity, the IRAF task `rvcorrect` was used. The final velocities obtained for the stars are given in Table 2.1. The measured values are in excellent agreement with values quoted in literature.

3 Line Measurement

The `splot` tool was used to plot the spectrum and mark out lines. Absorption lines of depth more than 0.9 (relative to the continuum) were marked out and gaussian profiles were fitted to the line features. The area under the gaussian profile gave the equivalent width of the line.

Table 2: Heliocentric radial velocities for HIP 99938 and HIP 3026

Star	Topocentric Velocity kms^{-1}	Heliocentric Velocity kms^{-1}
HIP 99938	-117.9 ± 0.3	-110.2 ± 0.3
HIP 3026	-21.4 ± 1.4	-28.0 ± 1.4

3.1 Equivalent Width

The equivalent width is a measure of the strength of the line expressed in terms of the equivalent width of the continuum in the neighbourhood of the line. In terms of wavelength units, it is defined as,

$$W_\lambda = \int_0^\infty \frac{f_c - f_\lambda}{f_c} d\lambda.$$

If the spectrum has been normalized with the continuum, the definition simplifies to,

$$W_\lambda = \int_0^\infty 1 - f'_\lambda d\lambda.$$

In theory the limits of the integral are from 0 to ∞, however in practice, because it is not possible to separate out the correct contributions of individual lines and because the area under the 'wings' of the profile is negligible, the integration is done for only a few Ångström around the line centre.

3.2 Identification

For line identification, FeI and FeII line data from the Atomic Spectral Line Database by R. Kurucz was used. Lines were marked out for identification using the `splot` task in *IRAF*. A C++ code was written to automatically compare these marked lines with the Kurucz database within an accuracy of 0.05 Ångströms. Only weak lines were chosen to avoid non-linearities due to non-zero opacity and micro-turbulence.

4 Measurement of Temperature and Abundances

We assume that the stellar atmosphere is in local thermodynamic equilibrium so that the atmosphere can be described with single temperature and surface gravity values. We also assume that the lines are optically thin (Line width $W \propto$ Abundance N). Using the Boltzmann equation we get,

$$W = \frac{N \mathrm{e}^2 \lambda^2 g f e^{-E_l/kT}}{4\epsilon_o m_e c^2 u},$$

where N is the column density of the ion species, E_l is the lower excitation potential of the line, gf is the statistical weight and probablility factor for the transition and u is the partition function for the species.

Taking log on both sides of the above equation, we obtain

$$\log \frac{W}{gf\lambda^2} = \log \frac{\mathrm{e}^2}{4\epsilon_\mathrm{o} mc^2} + \log N - \log u - \frac{E_l}{kT} \log e,$$

This equation reduces to, in SI units,

$$\log \frac{W}{gf\lambda^2} = -14.053 + \log N - \log u - \frac{5039.7 E_l}{T}$$

Hence, a plot of $\log \frac{W}{gf\lambda^2}$ against E_l for all lines of the same species must be a straight line with slope equal to $5039.7/T$. The constant term will give the value of the abundance $\log N$. The partition function u can be calculated from the power series

$$\log u = c_0 + c_1 \log \frac{5039.7}{T} + c_2 \log^2 \frac{5039.7}{T} + c_4 \log^3 \frac{5039.7}{T}.$$

The values of constants c_i can be obtained from standard tables. Table 4 lists the values for these tables for FeI and FeII.

Table 3: Power series coeffients for partition function calculation

Species	c_0	c_1	c_2	c_3
FeI	1.44701	-0.67040	1.01267	-0.81428
FeII	1.63506	-0.47118	0.57918	-0.12293

Plotting the data of the lines with the above equations we get,

Table 4: Temperature and FeI abundance for HIP 3026 and HIP 99938

Star	Temperature K
HIP 3026	6000 ± 500
HIP99938	6000 ± 1000

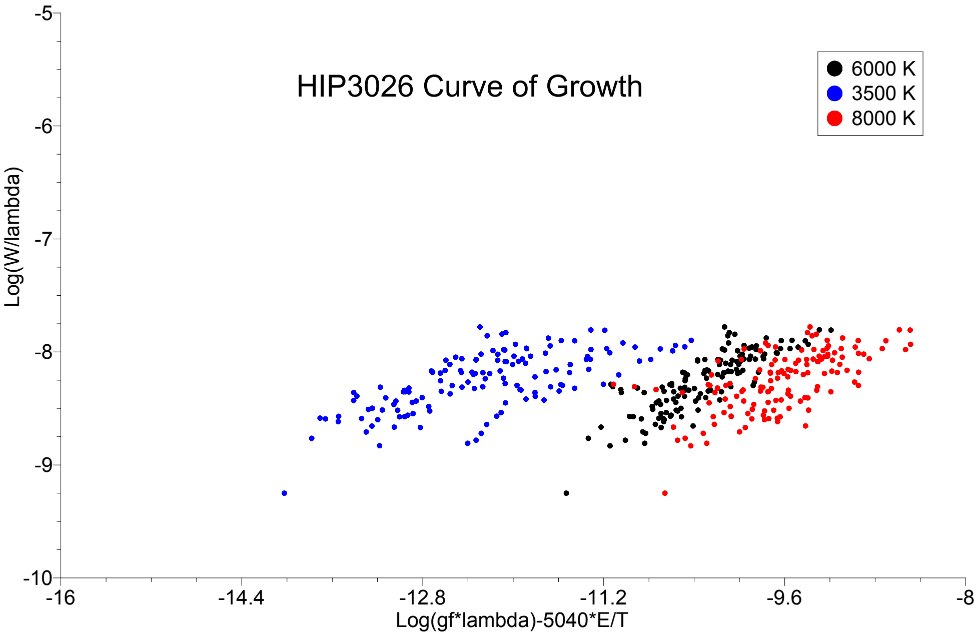
5 Discussion of Results

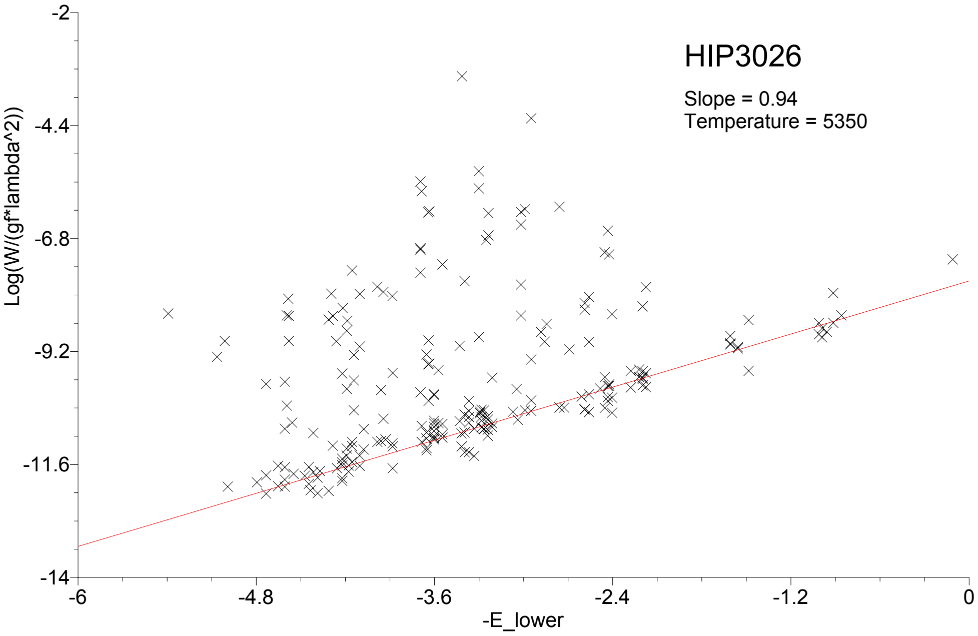
The graph of $\log \frac{W}{gf\lambda^2}$ against E_l for both the stars shows a significant scatter in the points. The graph for HIP 3026 shows a definite line with a few deviating points, however the graph for HIP 99938 has a very high scatter and we cannot get a definite temperature from it.

The high scatter of the points can be attributed to any of the following factors

- Inaccurate $\log gf$ values
- Inaccurate fitting of gaussian curves to strong lines
- Misidentification of lines

This can be further improved by using experimental $\log gf$ values in place of the theoretical values used and by not considering lines with broad wings. The third error seems to be small in this particular spectrum as the spectra are of high resolution and the identification has been done within the resolution of the spectra.


HIP3026 Curve of Growth
● 6000 K
● 3500 K
● 8000 K
Log(W/lambda)
-5
-6
-7
-8
-9
-10
-16
-14.4
-12.8
-11.2
-9.6
-8
Log(gf*lambda)-5040*E/T


HIP3026
Slope = 0.94
Temperature = 5350
Log(W/(gf*lambda^2))
-2
-4.4
-6.8
-9.2
-11.6
-14
-6
-4.8
-3.6
-2.4
-1.2
0
-E_lower

6 Further Work

The preceding calculations have determined the temperature of the stars and abundance of FeI. Further, with identification of lines of FeII, we can make use of Saha's equation to determine the electron density N_e in the atmosphere. Determination of N_e will allow the calculation of the surface gravity.

6.1 Saha's Equation

The Saha equation relates the abundances of the reactants and the products of the ionization reaction,

$$A \rightleftharpoons A^+ + e^-.$$

If n_A, n_{A^+} and n_e are the number densities of species A, A^+ and e^- respectively,

$$\frac{n_e n_A}{n_{A^+}} = \left(\frac{2\pi m_e kT}{h^2}\right)^{\frac{3}{2}} \frac{2u_A}{u_{A^+}} \exp\left(-\frac{\chi_A}{kT}\right)$$

where u_A and u_{A^+} denote the partition functions of A and A^+ respectively and χ_A denotes the ionization potential of A.

From the procedure described in the earlier sections, we can determine n_A, n_{A^+} and the temperature T. From these values and from the tabulated values of the partition functions, we can calculate the value of electron density n_e.

6.2 Current Methods

MOOG (by Chris Sneden) is a code that performs a variety of LTE line analysis and spectrum synthesis tasks. The typical use of MOOG is to assist in the determination of the chemical composition of a star.