

DETERMINATION OF METALLICITY OF THE HR7914 SOLAR-LIKE STAR

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SUMMARY: By using the Blackwell program package by R.O. Gray, the metallicity of the HR7914 solar-like star was determined. The program package utilizes measured equivalent widths of several chosen neutral iron spectral lines from the observed spectra, appropriate atomic and spectral line parameters and adequate Kurucz's stellar atmosphere models. The method is based on determination of the minimum dispersion of the iron abundance versus microturbulent velocity functions for the selected neutral iron spectral lines. The spectra were observed at National Astronomical Observatory Rozhen (NAO Rozhen), Bulgaria, using the 2m-telescope and Coude spectrograph. They were reduced with the IRAF program package. The measurement of the spectral line parameters was done with the SPE program package. The metallicity of the HR7914 solar-like star was determined to be 0.02.

Key words. Stars: abundances – Methods: observational – Techniques: spectroscopic

1. INTRODUCTION

The observed parameters of the MnI 539.47 nm spectral line profile in the solar spectra suffered unusually large variation with solar cycle (Livingston 1992, Vince and Erkapic 1998). Such large variation could be due to the high temperature sensitivity of this line that was determined experimentally. The method was based on the observations of several solar-like stars, measurements of the variations in the MnI 539.47 nm spectral line profile parameters (equivalent width (EW), central depth (CD) and full width at half maximum (FWHM)) with effective temperature, and on derivation of their temperature gradients for the solar effective temperature (Vince et al. 1998, Vince and Vince 2001). The method was applied to all available observations of the solar-like stars. In order to get more accurate results, a few corrections were made on the observational data:

corrections for stellar rotation, stellar macroturbulent velocity, instrumental profile and metallicity of both, spectral line profile parameters and B-V color index (Vince 2003). To accomplish the later two corrections it was necessary to find the values of metallicity for all considered stars. Unfortunately, for several stars the metallicity could not be found in the catalogues and had to be determined.

In this paper, the procedure used to determine the metallicity is described on an example of the HR7914 solar-like star. Blackwell program package by R.O. Gray,¹ was used. Blackwell program package utilizes equivalent widths of several neutral iron spectral lines measured from the observed spectra, appropriate iron atomic and neutral iron spectral line profile parameters and adequate Kurucz's stellar atmosphere models.

The method is based on determination of the minimum dispersion of the functions (that is, at iron abundance dependence on the microturbulent velo-

¹<http://www.phys.appstate.edu>

Table 1. The parameters of the spectrograph (width of the entrance slit (W), focal length of the colimator mirror (f_{col}), type of the grating (type), size of the grating (Sz), number of grooves per millimeter (Gr), blazing angle (Bz), focal length of the camera mirror (f_{cam}).

$W[\mu\text{m}]$	$f_{col}[\text{mm}]$	type	$Sz[\text{cm} \times \text{cm}]$	$Gr[\text{l}/\text{mm}]$	$Bz[^\circ]$	$f_{cam}[\text{mm}]$
300	7200	Baush&Lomb	32×32	632	22.3	1900

city calculated by Blackwell program package) for selected neutral iron spectral lines using the above mentioned data. As a result, the stellar iron abundance and the microturbulent velocity can be obtained. This simultaneous determination of the unknown quantities is the advantage of this method. With iron abundance of the star obtained in this way and with the known iron abundance of the Sun, the determination of the star metallicity is straightforward.

2. OBSERVATION, REDUCTION AND MEASUREMENT

The spectrum of the solar-like star HR7914 was taken at NAO Rozhen, Bulgaria, using 2m RCC telescope and Coude spectrograph. The geographical coordinates of the Observatory are: $\varphi = 41^\circ 41' 35''$, $\lambda = 24^\circ 44' 38''$ and $h = 1759$ m.

Relevant parameters of the observed star are: $\alpha_{2000} = 20\text{h } 40\text{m } 45.1\text{s}$, $\delta_{2000} = 19^\circ 56' 07''$, $m_V = 6.45$ and spectral class is G5V.

Some technical characteristics of the spectrograph are presented in Table 1.

The spectrograph provides spectral resolution of about 30 000. During the observation we tried to achieve signal-to-noise ratio of 300.

Further reduction and calibration of the data were carried out by means of the IRAF (Image Reduction and Analysis Facility) program package. The measurement of the iron spectral line profile parameters was carried out by means of the SPE (One-Dimensional Reduction and Analysis of Spectra) program package.

3. INPUT DATA

3.1. Equivalent widths

Spectral lines used for the determination of metallicity were selected from Rutten's list of clear (unblended) solar spectral lines (Rutten and Van der Zalm 1984). For all these lines the excitation potential of lower energy level of the transition is approximately the same. This is important because the curve of growth depends on the excitation potential. A part of the observed spectrum with the chosen spectral lines is shown on Fig. 1.

The measured equivalent widths of the observed iron spectral line profiles which were used for stellar metallicity determination are presented in Table 2.

Table 2. Measured equivalent widths of the neutral iron spectral lines used for stellar metallicity determination.

$\lambda[\text{\AA}]$	$EW_{HR7914}[\text{\AA}]$
5379.581	0.052307
5386.340	0.027167
6226.740	0.028258
6232.648	0.083067

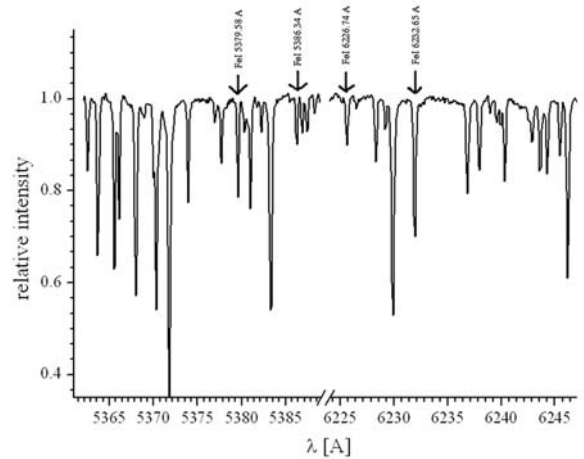


Fig. 1. The spectral lines used for the determination of metallicity of the solar-like star HR7914.

3.2. Atomic and spectral line parameters

The iron atomic and spectral line parameters were taken from NIST Atomic Spectra Database². Wavelengths of the selected neutral iron spectral lines with some relevant iron atomic and neutral iron spectral line parameters are presented in Table 3.

Table 3. The list of spectral lines used for solar-like star HR7914 metallicity determination. The columns show wavelength in \AA , lower and higher energy levels in cm^{-1} , $\log(gf)$, excitation potential of lower energy level in eV.

$\lambda[\text{\AA}]$	$E_i[\text{cm}^{-1}]$	$E_j[\text{cm}^{-1}]$	$\log(gf)$	$\chi[\text{eV}]$
5379.581	29799	48383	-1.58	3.6946
5386.340	33507	52067	-1.81	4.1544
6226.740	31323	47378	-2.16	3.8836
6232.648	29469	45509	-1.22	3.6537

²<http://physics.nist.gov>

3.3. Kurucz's stellar atmosphere models

Kurucz's stellar atmosphere models used by Blackwell program package to determine the stellar metallicity as well as the program package to select the specific model can be found on the Internet³. The selection is performed according to the stellar effective temperature (T_{eff}) and the logarithm of surface gravity ($\log(g)$). The effective temperature and the logarithm of surface gravity of the solar-like star HR7914 are $T_{eff}=5650$ K and $\log(g)=4.42$, respectively. Since models which corresponds to these values are not contained in Kurucz's stellar atmosphere models (there are only models with $T_{eff} \in \{\dots, 5500\text{K}, 5750\text{K}, 6000\text{K}, \dots\}$ and $\log(g) \in \{\dots, 3.5, 4.0, 4.5, \dots\}$), the interpolation should be carried out.

Thus, the model with $T_{eff}=5650$ K and $\log(g)=4.42$, adequate for the star considered has been obtained after three successive interpolations:

- interpolation of models with $T_{eff}=5600$ K and $\log(g)=4.0$ and $T_{eff}=5750$ K and $\log(g)=4.0$ in order to obtain model with $T_{eff}=5650$ K and $\log(g)=4.0$,
- interpolation of models with $T_{eff}=5600$ K and $\log(g)=4.5$ and $T_{eff}=5750$ K and $\log(g)=4.5$ in order to obtain model with $T_{eff}=5650$ K and $\log(g)=4.5$,
- interpolation of models with $T_{eff}=5650$ K and $\log(g)=4.0$ and $T_{eff}=5650$ K and $\log(g)=4.5$ in order to obtain model with $T_{eff}=5650$ K and $\log(g)=4.42$.

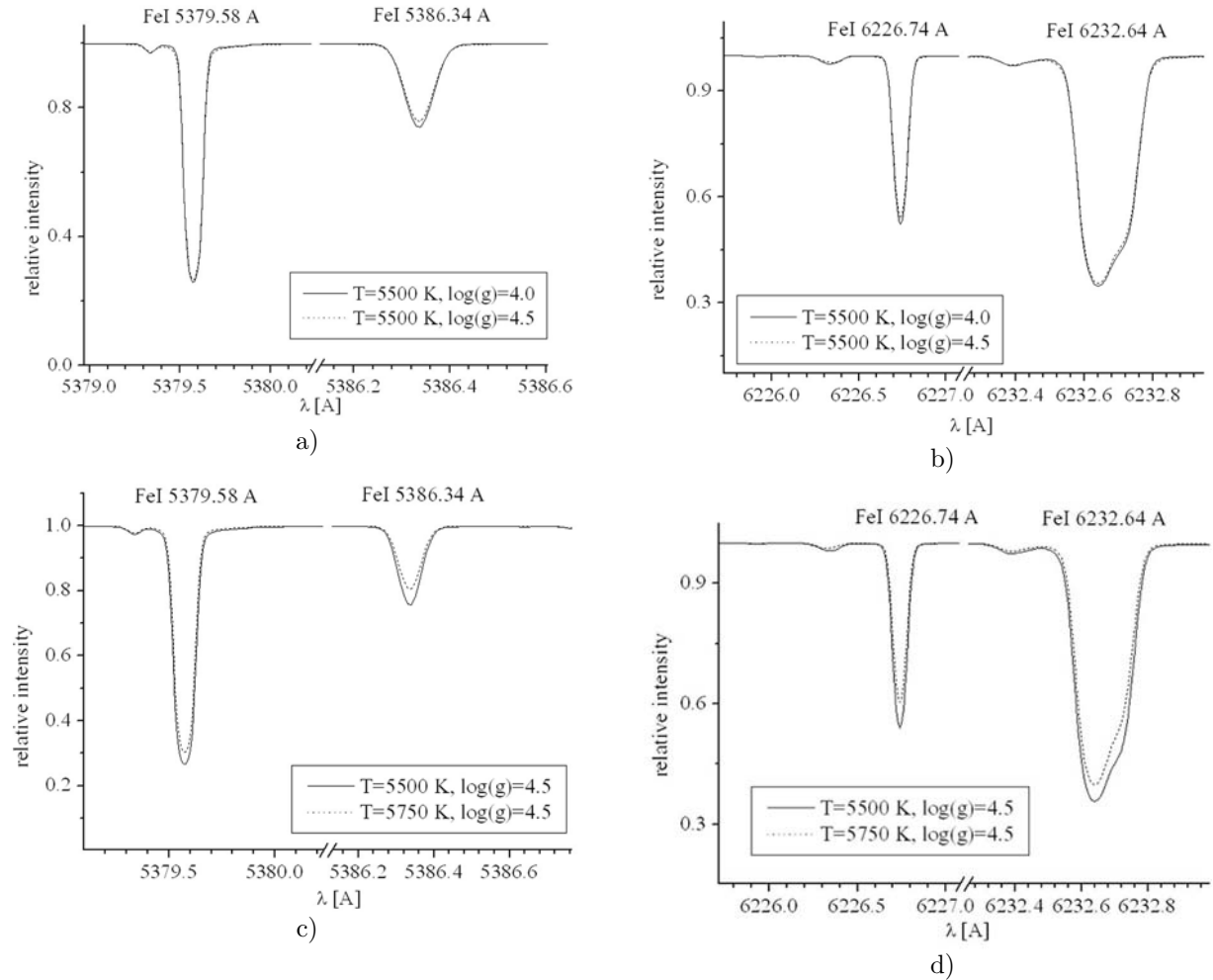


Fig. 2. Modification of absorption spectrum obtained by SPECTRUM program package, varying the logarithm of surface gravity (a,b), and the effective temperature (c,d).

³<http://www.phys.appstate.edu>

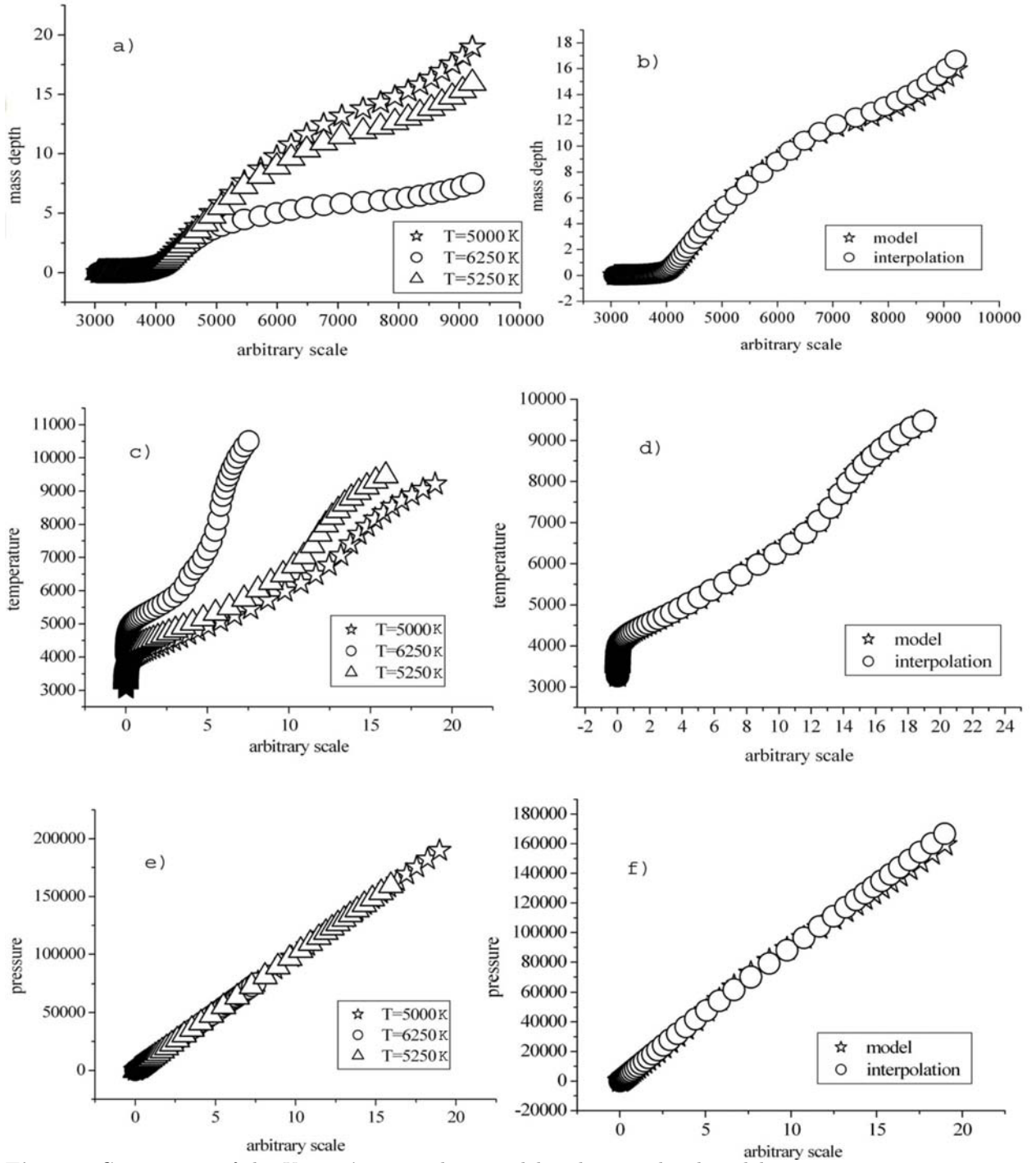


Fig. 3. Comparison of the Kurucz's atmosphere model and interpolated model parameters.

Table 4. Relative change of spectral line equivalent widths with changing the effective temperature and logarithm of surface gravity.

	FeI 5379.58 Å	FeI 5386.34 Å	FeI 6226.74 Å	FeI 6232.64 Å
$T_{eff}=\text{const}, \log(g)\neq\text{const}$	1.6 %	3.1%	2.5%	0.9%
$T_{eff}\neq\text{const}, \log(g)=\text{const}$	11.1%	22.2%	17.7%	12.2%

This is rather arduous work. Therefore, we have estimated the amount by which the spectrum in the vicinity of the chosen spectral lines is changed when the effective temperature is changed by 250 K (with constant logarithm of surface gravity) on one hand, and when the logarithm of surface gravity changes by 0.5 (with constant effective temperature) on the other hand. Figs. 2a and b show the absorption spectrum obtained by the SPECTRUM program package using models with the same effective temperature and different values of the logarithm of the surface gravity, whereas Figs. 2c and d show the same as Figs. 2a and b provided that logarithm of surface gravity was the same for the models of different effective temperatures. From Fig. 2 it is obvious that the spectrum is changed only slightly by changing the logarithm of surface gravity and significantly changed by changing the effective temperature. Table 4 presents the relative change of spectral line equivalent widths. Only the interpolation with respect to the effective temperature was applied in this computation.

Fig. 3 illustrates to what extent the models are changed by interpolation. Namely, Figs. 3a, c and e represent the run of the mass depth, temperature and pressure for two Kurucz's stellar atmosphere models ($T=5000$ K and $T=6250$ K) and for the model obtained by their interpolation ($T=5250$ K). The interpolation was done for effective temperature of 5250 K in order to be able to compare the obtained interpolated model with the corresponding Kurucz's one. The comparison is illustrated on Fig. 3b, d and f for the run of mass depth, temperature and pressure respectively. The resemblance of the interpolated model and Kurucz's stellar atmosphere model is obvious.

4. CALCULATIONS AND RESULTS

Using parameters given in Tables 2 and 3 and the appropriately interpolated Kurucz's atmosphere model, Blackwell program package gives iron abundance vs. microturbulent velocity for selected neutral iron spectral lines. The results are shown in Fig. 4a.

Minima of the dispersion of the functions (that is iron abundance versus microturbulent velocity for selected neutral iron spectral lines) correspond to the most probable value for microturbulent velocity and iron abundance of the considered star.

A more convenient way to determine the minima of the function dispersion is to compute the standard deviation of the iron abundance for each value of the microturbulent velocity:

$$\sigma = \sqrt{\sum_{i=1}^n \frac{(\log(Fe/H)_m - \log(Fe/H)_i)^2}{n-1}}, \quad (1)$$

(where: $\log(Fe/H)_m$ is the mean value of the iron abundance for the specific value of the microturbulent velocity) in order to obtain diagram given in Fig.

4.b) of the standard deviation versus microturbulent velocity for the star under consideration.

With the value for stellar iron abundance ($\log(Fe/H)$) derived in such a way and with the knowledge the iron abundance of the Sun ($\log(Fe/H)_\odot$) the metallicity of the star can be obtained from the equation:

$$[Fe/H] = \text{rm} \log(Fe/H) - \text{rm} \log(Fe/H)_\odot \quad (2)$$

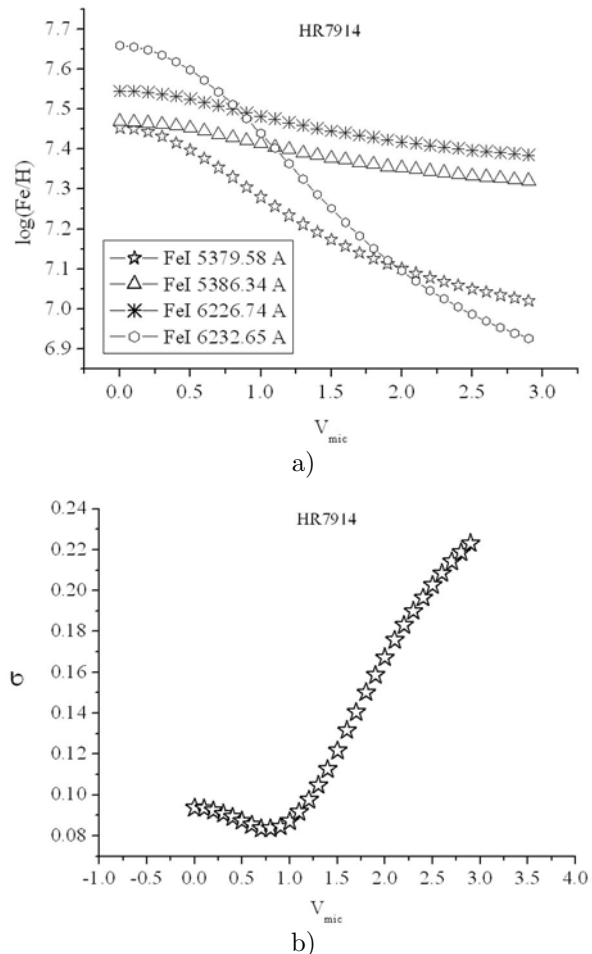


Fig. 4. Iron abundance vs. microturbulent velocity for solar-like star HR7914 a), standard deviation in relation to microturbulent velocity for the same star b).

The result of the stellar metallicity determination performed by Blackwell program package is presented in Table 5.

Table 5. Microturbulent velocity, iron abundance and metallicity of the star obtained by means of the Blackwell program package.

HR	V_{mic} [km/s]	$\log(Fe/H)$	$[Fe/H]$
7914	0.7	7.46	0.02

For the iron abundance of the Sun, the value of 7.44 was used (Bellot Rubino and Borrero 2002).

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ОДРЕЂИВАЊЕ МЕТАЛИЧНОСТИ ЗВЕЗДЕ СУНЧЕВОГ ТИПА HR7914

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Претходно саопштење

У овом раду одређивана је металичност звезде HR7914 коришћењем програмског пакета BLACKWELL. За одређивање металичности, програмски пакет користи: еквивалентне ширине неколико изабраних спектралних линија неутралног гвожђа мерене из посматраних спектра, атомске параметре гвожђа, одговарајуће параметре изабраних спектралних линија неутралног гвожђа и одговарајуће Курцове моделе звезданих атмосфера. Посматрани спектри су добијени на Националној астрономској опсерваторији на Рожену

(National Astronomical Observatory at Rozhen) у Бугарској са RCC телескопом пречника објектива 2m и Куде спектрографом. Обрада посматрања и мерење еквивалентних ширина вршено је помоћу IRAF односно SPE програмских пакета. Принцип рада BLACKWELL програмског пакета заснива се на одређивању минималне дисперзије релативне заступљености гвожђа у функцији од микротурбулентне брзине за изабране спектралне линије гвожђа које даје програмски пакет. За металичност звезде добијена је вредност 0.02.