High resolution spectroscopy of halo stars within the spectral region 3550–5000 Å

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ABSTRACT

High resolution echelle spectroscopy in ground-based UV is a powerful facility for study of chemical evolution of early Galaxy.

An atlas of high resolution (R = 60000) in the poor studied wavelength range 3550–5000 Å for 4 metal-deficient stars in the interval of metallicity $-3.0 < [Fe/H] < -0.6$, effective temperature $4750 < T_{\text{eff}} < 5900$ K, surface gravity $1.6 < \log g < 5.0$ is produced. Details of the method of producing a spectral atlas, line identifications, stellar atmospheric parameters determination are described. Based on these spectral data, we determined model atmosphere parameters and calculated abundances of 25 chemical elements.

Key words: Ground-based UV and blue astronomy, high resolution spectroscopy, metal-poor stars, chemical composition, spectral atlas

1. Introduction

During last decades we see a large growth of scientific interest in study of the old extremely metal-poor stellar population. Search for stars of first generations in Galaxy is a key program at largest telescopes in world since chemical evolution of Galaxy in whole is imprinted in chemical abundances pattern in atmospheres of stars of following generations. Reconstruction of chemical evolution of Galaxy requires an enormous number of highly qualitative spectra of metal deficient stars. We undertake to high resolution spectroscopy of old stars at the 6 m telescope of the Special Astrophysical Observatory RAS. Below we present some results.
2. Spectral observations and atlas producing

We have selected a sample of metal-poor stars to obtain their evolution status and detailed chemical composition. Some characteristics of 4 first stars and model parameters adopted are presented in Table 1. The spectra were obtained using the echelle spectrograph NES (Panchuk et al., 2007) permanently mounted in a Nasmyth focus. NES provides a spectral resolving power of $R \geq 60000$ in the range 3200–10000 Å. A possibility to observe in UV was given thanks to creation of an echelle spectrograph NES with a camera from fused silica. NES works in combination with a CCD 2048x2048 pixels having a high sensitivity in a blue spectral range.

The 2D spectra were reduced (applying standard procedures of bias subtraction, scattered light and cosmic ray trace removal, and order extraction) using the context ECHELLE under MIDAS (version 01FEB). To process spectra obtained with an image slicer the context ECHELLE was modernized (Yushkin & Klochkova, 2004). The signal-to-noise ratio for all the spectra shown in this atlas is higher than 200. Combined with the spectral resolving power, that allowed us not only to detect rather weak lines but also to study their profiles. To illustrate an effect of difference in metallicity, full spectra of 2 stars with significantly distinguished metallicity are presented in Fig. 2. Such a scale illustrates very well a role of blanketing effect. Large details, Balmer lines (especially $\text{H}_\gamma$ and $\text{H}_\beta$), Ca II doublet, are clearly seen.

![Figure 1: Comparison of the spectra of two stars with very distinguished metallicity (G37–26, [Fe/H]=−2.04, and G27–44, [Fe/H]=−0.60 within the full spectral region registered.](image)

We made the atlas as intensities, normalized to the continuum, versus laboratory wavelengths in the range 3550–5000 Å. The atlas includes 29 spectral fragments approximately 60 Å in width. As an example, the region $\lambda$3550–3600 Å is shown in Fig. 2. For orientation in the identification some principal details used for chemical composition calculation are marked. The lines in the spectra were identified using the
Table 1: Basic data and model atmospheric parameters of stars studied

| Star    | V     | \( \pi \), mas | \( T_{\text{eff}} \), K | \( \log g \) | [Fe/H] | \( \xi_t \), km/s |
|---------|-------|-----------------|-------------------------|------------|--------|------------------|
| G27-44  | 7.411 | 23.66           | 4975                    | 4.35       | −0.60  | 1.0              |
| HD 188510| 8.832 | 25.32           | 5475                    | 5.00       | −1.52  | 0.6              |
| G37-26  | 8.056 | 25.85           | 5900                    | 4.50       | −2.04  | 0.7              |
| HD 115444| 8.975 | 3.55            | 4750                    | 1.60       | −2.91  | 1.7              |

The initial list of lines includes about 8100 lines. Based on the solar spectrum, about 860 unblended lines were selected. Quality of spectra in near UV-region permits us to begin the task of cosmochronology (see Th and Nd lines in Fig. 3).

3. Model parameters and elemental abundances

The effective temperature \( T_{\text{eff}} \) was derived using the Stromgren indices \((b - y, c_1)\) and the calibration based on the method of infrared flux (Alonso et al., 1996). The metallicity values needed for the first iteration of \( T_{\text{eff}} \) determination were used from publications, but in the following iterations our spectroscopic [Fe/H] values were used. In such a procedure for different stars from 100 to 230 Fe line values were used. Besides, to control the \( T_{\text{eff}} \) values we added the generally used spectroscopic way \( T_{\text{eff}} \).
determination – a forcing of independence of $\lg \epsilon(Fe)$ on low level excitation potential. A surface gravity were calculated based on known relations:

$$\lg \frac{g}{g_\odot} = \lg \frac{M}{M_\odot} + 4 \lg \frac{T_{\text{eff}}}{T_{\text{eff,}\odot}} + 0.4(M_{\text{bol}} - M_{\text{bol,}\odot}),$$

where: $M_{\text{bol}} = V + BC + 5 \lg \pi + 5$, $M$ – a mass of a star, $M_{\text{bol}}$ – bolometric luminosity, $V$ – visual magnitude, $BC$ – bolometric correction, $\pi$ – stellar parallax.

The Hipparcos parallaxes were attracted for calculations. The stellar masses were determined using the evolution tracks by Vandenberg et al. (2000) calculated with a step in metallicity $\approx 0.1$ dex. Bolometric corrections were calculated using the calibration formula by Balona (1994). The microturbulent velocity $\xi_t$ was determined forcing the independence of neutral iron abundance on equivalent width $W_\lambda$ of the line. The programme WIDTH9 and the Kurucz’s grid of the atmospheric models were used for chemical abundances calculation.

From comparison our results for the star HD 115444 with data by Westin et al. (2000) for overlapping elements we obtained systematic deviation about 0.1 dex which is caused by using of different systems of oscillator strengths and models parameters adopted. For most of chemical elements we obtained typical for their metallicity chemical abundances picture. For example, $\alpha$-process elements Mg, Ca, Ti are over-abundant for stars of low metallicity.

Summary

For the first time an unique atlas of F–K-stars spectra of very low metallicities is produced. An atlas is produced for the range 3550–5000 Å with a high spectral resolution $R = 60000$. The lines identification was performed by the models atmospheres method. More detailed results will be published in a forthcoming paper by Klochkova et al. (2006). The atlas in whole, $W_\lambda$, atomic data and abundances calculated are...
Table 2: Relative abundances of chemical elements \([X/Fe]\)

| Species | \([X/Fe]\) = (\(\lg \epsilon(X) - \lg \epsilon(Fe)\)) - (\(\lg \epsilon(X) - \lg \epsilon(Fe)\))⊙ | G27-44 | HD 188510 | G37-26 | HD 155444 |
|---------|---------------------------------------------------------------------------------|--------|----------|--------|----------|
| Na1     | -0.12                                                                           |        |          |        |          |
| Mg1     | +0.16                                                                           | +0.27  | +0.55    |        | +0.77    |
| Al1     | -0.65                                                                           | -0.93  | -0.72    |        | -0.12    |
| Si1     | -0.24                                                                           | -0.27  | +0.11    |        | +0.53    |
| Ca1     | +0.31                                                                           | +0.43  | +0.53    |        | +0.48    |
| Sc2     | +0.37                                                                           | +0.25  | +0.19    |        | +0.23    |
| Ti1     | +0.06                                                                           | +0.19  | +0.31    |        | +0.35    |
| Ti2     | +0.20                                                                           | +0.32  | +0.37    |        | +0.41    |
| V1      | +0.03                                                                           | +0.06  | +0.14    |        | +0.16    |
| V2      | +0.32                                                                           | +0.25  | +0.13    |        | +0.17    |
| Cr1     | -0.01                                                                           | +0.04  | -0.05    |        | -0.23    |
| Cr2     | +0.20                                                                           | +0.18  | +0.16    |        | +0.23    |
| Mn1     | -0.10                                                                           | -0.27  | -0.33    |        | -0.47    |
| Fe1     | +0.00                                                                           | -0.00  | +0.01    |        | -0.00    |
| Fe2     | -0.00                                                                           | +0.00  | -0.01    |        | +0.00    |
| Co1     | +0.13                                                                           | +0.19  | +0.27    |        | +0.36    |
| Ni1     | -0.09                                                                           | -0.04  | -0.09    |        | -0.01    |
| Zn1     | -0.08                                                                           | +0.09  | +0.10    |        | +0.26    |
| Sr2     | -0.03                                                                           | -0.35  | +0.16    |        | +0.07    |
| Y1      | +0.10                                                                           | -0.00  | +0.01    |        | +0.04    |
| Zr2     | +0.06                                                                           | +0.43  | +0.36    |        | +0.35    |
| Ba2     | +0.21                                                                           | +0.10  | +0.26    |        | +0.72    |
| La2     | +0.23                                                                           | +0.30  |          |        | +0.33    |
| Ce2     | +0.25                                                                           | +0.38  | +0.37    |        | +0.35    |
| Nd2     | +0.45                                                                           | +0.73  | +0.48    |        | +0.60    |
| Sm2     | +0.31                                                                           | +0.82  | +1.41    |        | +0.77    |
| Eu2     | +0.66                                                                           | +0.76  | +0.14    |        | +1.26    |
| Gd2     | +0.30                                                                           | +1.49  |          |        | +0.96    |
| Dy2     | +0.31                                                                           | +0.57  |          |        | +0.74    |
available by web access to [http://www.sao.ru/hq/ssl/Atlas-UV/Atlas-UV.html](http://www.sao.ru/hq/ssl/Atlas-UV/Atlas-UV.html). A comparison of the spectra of stars may help in a search for new spectroscopic criteria to distinguish metal deficient stars. In this connection several spectroscopic features are particularly interesting. Such spectra could be useful for studies both of the chemical abundances of separate stars and determination their evolution stages. The atlas provides a spectral library for population synthesis. Besides a large number of spectral lines sufficient for calculation of numerous elements abundances, a short wavelengths range has another advantage in task of chemical composition determination. For temperature and pressure values typical for subdwarf atmospheres a coefficient of extinction in continuum near 4000 Å is lower about 0.2 dex than in red part of spectra. It means that continuum extinction arises deeper in atmosphere than that in red range (near 6000 Å). Therefore, weak short wavelengths lines are formed in average closer to photosphere than longer wavelengths lines. It permits to hope that a model description of short wavelengths line is more accurate than the longer wavelengths lines.

**Acknowledgements:**

Our work was supported by the Russian Foundation for Basic Research (project 05–07–90087b) and the Russian Federal program “Observational manifestations of evolution of chemical abundances of stars and Galaxy”.

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