THE STARS OF THE LOW PART OF MAIN SEQUENCE

T.V. Mishenina[1], S.I. Belik[1], I.A. Usenko[1], O. Bienaymé[2], C. Soubiran[3], V.V. Kovtyukh[1], S.A. Korotin[1]

[1]Astronomical Observatory, Odessa National University
T.G.Shevchenko Park, Odessa 65014 Ukraine, *astro@paco.odessa.ua*
[2]Observatoire Astronomique de l'Universitté Louis Pasteur
11 rue de l'université, Strasbourg, France
[3]Observatoire Aquitain des Sciences de l'Univers
CNRS UMR 5804, BP 89, 33270 Floirac, France

ABSTRACT. Atmospheric parameters (T_{eff}, $\log g$, [Fe/H], V_t), Li, and volatile (O, Na, Al, Zn) and refractory (Si, Ti, V, Cr, Co and Ni) element abundances in 133 stars belonging to the low part of MS have been determined. Among them about 30 stars are the variable stars of BY Dra type, for which the determination of the chemical composition was made for the first time. The effective temperatures T_{eff} were estimated by the line depth ratio method. The surface gravities $\log g$ were determined by two methods (ionization balance of iron and using parallaxes). The abundances of lithium and oxygen were determined by the calculation of synthetic spectrum. The comparison of volatile and refractory element abundances in variable stars and other stars was made. We have found that the behaviour of the abundances of the majority of elements in MS stars and spotted stars does not differ. The Li is detected in 65 % BY Dra stars and in 26 % of MS stars. The Li abundance in variable stars is higher than in MS dwarfs.

Key words: Stars: fundamental parameters; stars: abundances; stars: main -sequence; stars: BY Dra type.

1. Introduction

In the cadre of the program of determination by a uniform technique of parameters and a chemical composition for the extensive sample of stars we represent the investigation of 133 stars of the low part of the Main Sequence (MS). Among the stars selected by us for this work more than 30 ones are variable stars belonging to a class of flashing stars, and, basically, to a subclass of BY Dra type stars. Till now any detailed spectral investigation of the chemical composition of this type stars has not been made. As a rule, spectral researches of these stars were spent for the analysis of spots on their surface. Thus, there is the unique opportunity to analyse chemical peculiarities of these stars for the first time. As all stars studied by us in the given work belong to solar type, and many researchers classify the Sun as a star of BY Dra type, it would be obviously important to investigate: 1) the general behaviour of various element abundances with metallicity [Fe/H] , 2) dependences (trends) of volatile and refractory element abundance with [Fe/H] which can testify in favour of presence of planetary systems in dwarfs and variable stars, 3) the lithium abundance as the indicator of activity and age of stars. The goals of our work are the determination of the atmospheric parameters for stars of the low part of MS, the analysis of the spectral peculiarities and the chemical composition (abundances of Li and volatile and refractory elements).

2. Observations and spectral processing

Our target stars were selected upon photometric criterion M_V, (B-V) as stars belonging to low part of MS, where $M_V = V + 5 + 2.5\log \pi$. The spectral classes Sp, magnitudes V, color index (B-V) and type of variability were taken from SIMBAD database, the parallaxes π from Hipparcos catalogue (ESA 1997).

The spectra of 133 stars (F-G-K V) were obtained using the 1.93 m telescope of the Haute-Provence Observatoire (France) equiped with échelle-spectrograph ELODIE. The resolving power was 42000, the region of the wavelengths was 4400 - 6800 ÅÅ, the signal-to-noise ratio was about 130-230 (at 5500 Å). The primary processing of spectra (the image extraction, cosmic particles removal, flatfielding etc.) was carried out by following Kats et al. (1998). The further processing of spectra (continuum level location, measurement of the equivalent widths etc.) was performed using the software package DECH20 (Galazutdinov, 1992).

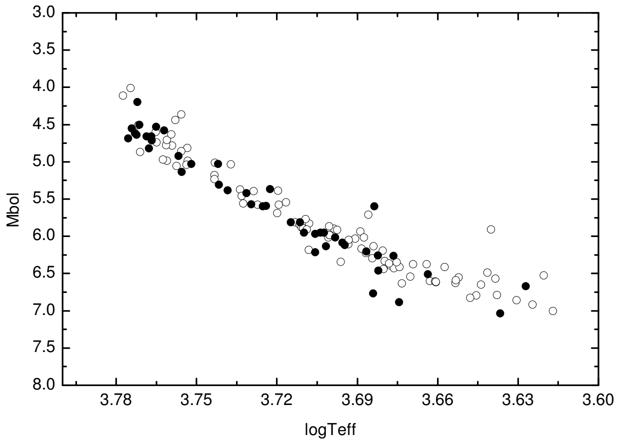

Figure 1: Location in the H-R diagram of MS (open circles) and variable (black circles) stars studied in this work.

The equivalent width are measured by gaussian fitting.

3. Peculiarities of spectra

The position of our target stars in the H-R diagram is given in Fig.1.

Bolometric magnitude M_{bol} was determined upon the dependence: $M_{bol} = M_V + BC$, where the bolometric corrections BC were taken from Flower (1996). Among our studied stars there are more than 30 variable flashing or active stars. The big class of flashing (Fl) stars (generally UV Cet type) is divided into subclasses, including, the spotted short-amplitude stars of BY Dra type (Chugainov, 1966) having the spectral types F – M V and vsini < 20 km s^{-1}, and RS CVn type stars that are the detached or semi-detached systems with components which have Sp: F-G V-IV and G-K IV. The masses of flashing stars are within the limits of 1.5 to 0.05 $M_{\odot}$, they have age from 10^6 to 10^9 years, and the period of axial rotation is from about 10 hours to about 10 days. For BY Dra type stars the differential rotation of a solar type (equator rotates faster than poles) and cycles of activity (similar to solar 11 years) were found (Gershbrg, 2002).

Previous photometric and spectral researches of flashing stars have been directed on study of temperatures and areas of spots. Application of photometric methods and modelling has allowed to construct the zonal spottedness model by Alekseev (2006), that was applied to the Sun, to BY Dra (Alekseev & Gershberg, 1996), to RS CVn (Alekseev & Kozhevnikova, 2005). Polarization methods show that the magnetic fields are located on the same active longitudes, as most spotarea. Some successes have been reached by the usine of the doppler imaging + zeeman spectroscopy of the high resolution spectra. Estimations of spots temperature have been made, basing on calibrations of the ratios of line intensity. There are in our list some known stars of BY Dra type: V439 And, V435 And, V538 Aur, OU Gem, DX Lyn, HP Boo, V1654 Aql, V1803 Cyg, HN Peg, V453 And, V833 Tau; and of RS CVn type – SV LMi, V368 Cep, V774 Her (Fl) and V775 Her. We found that four stars of our list show H_{α} emission. Unfortunately, spectra do not contain the region of H and K Ca II lines that are more reliable indicator of stars chromosphere and spotted activity. Absence of the obvious attributes of activity has allowed us to assume, that the spectra have been received in a quiet stars condition and we can apply to them standard methods of investigation.

4. Parameter determination

Stars of BY Dra type have, basically, the insignificant fluctuations in (B-V), that is not exceeding $0.^m1$. There are only some stars with changes of (B-V) up to 0.4. Nevertheless, using of the photometric calibrations to determine T_{eff} leads to significant errors in the temperature values. For example, d(B-V) = 0.02 gives the error in T_{eff} is equal to ±40 K and d(B-V) = 0.10 gives one about ±170 K. In our work the effective temperatures T_{eff} were estimated by the line depth ratio method which provides accuracy $\Delta\ T_{eff} = \pm 5 - 10$ K. Thus the received temperature characterizes the given current condition of an atmosphere that is very important in case of variable stars researching. To analyse the obtained T_{eff} we have looked on Figs.2,3, where dependences of $\sigma\ T_{eff}$ for obtained T_{eff} and stellar magnitude V are given. As can see the scatter does not exceed ±10 K on the average and is increasing up to 30 K at low temperatures (T_{eff} < 4400 K) and for faint stars (V < 9^m), i.e. it is due to lines blending and the low values of a signal to noise ratio (S/N) in the spectra of cool and faint stars, but MS stars and variable stars do not show any distinctions.

The surface gravities log g were determined by two methods (ionisation balance of iron and using the parallaxes), the average difference between two values obtained by these methods is $< \log g_{IE} - \log g_{\pi} >$ = -0.06 ±0.16 (for T_{eff} > 5000 K, 80 stars). The results of these two methods of applications are in the good agreement. The microturbulent velocity V_t was determined on the independence of the iron abundance log A(Fe) obtained from given Fe I line from equivalent width EW of this line. With the purpose of estimation of the parameters reliability and opportunities of their use in the analysis of variable stars, we have constructed also the dependence of turbulent velocity V_t on temperature T_{eff} (Fig.4).

As can see from the Fig.4, five stars show V_t values above 1.6 km s^{-1}, four of them are variables. However, for other stars, we do not observe distinctions for MS dwarfs and variable stars. The [Fe/H] metallicity is

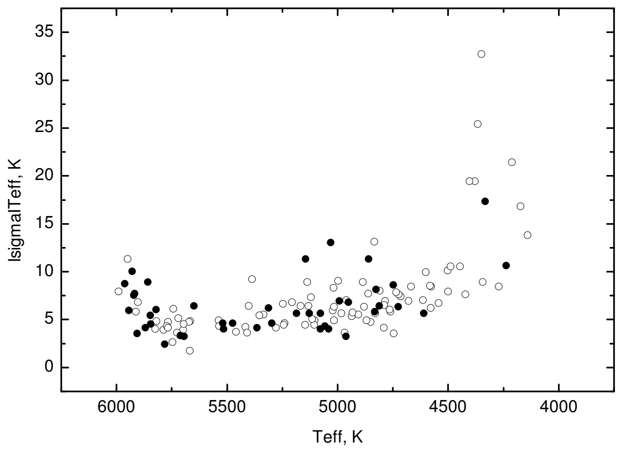

Figure 2: The dependences of σ T_{eff} on obtained T_{eff} for our studied stars, the notation is the same as in Fig.1.

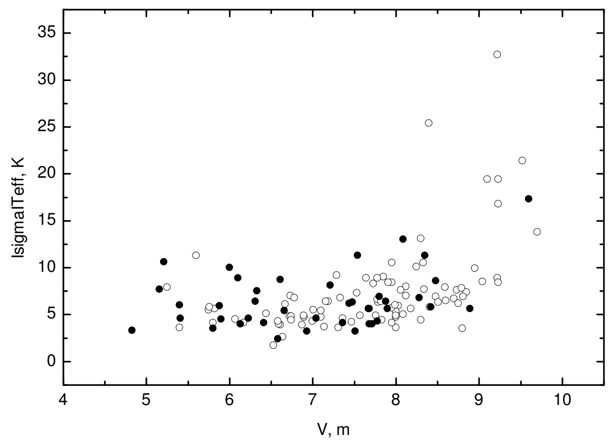

Figure 3: The dependenes of σ T_{eff} on stellar magnitude V for our studied stars, the notation is the same as in Fig.1.

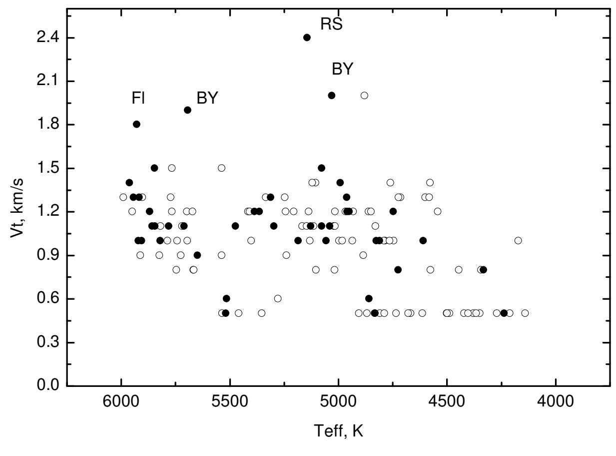

Figure 4: The dependences of V_t on obtained T_{eff} for our studied stars, the notation is the same as in Fig.1.

obtained as the iron abundance determined from Fe I lines. The accuracies of the parameter determination are: Δ T_{eff} = ±30 K, $\Delta \log g = \pm 0.3$ dex, Δ V_t =0.2 ± km s^{-1}.

5. Determination of chemical composition

We employ the grid of stellar atmospheres from Kurucz (1993) to compute abundances of Li, volatile (O, Zn, Na, Al) and refractory (Si, Ca, Sc, Ti, V, Cr, Co and Ni) elements. The choice of the model was made using the standard interpolation on T_{eff}, and $\log g$. The abundance analysis of Na, Al, Si, Ti, V, Cr, Co, Ni, and Zn has been done in the LTE approximation (Kurucz's WIDTH9 code) using the measured equivalent widths of these elements' lines and the solar oscillator strengths (Kovtyukh & Andrievsky, 1999). The Li abundances in program stars were obtained by fitting synthetic spectra to the observational profiles. We used STARSP LTE spectral synthesis code developed by Tsymbal (1996). Considering a wide range of temperatures and metallicities of our sample stars, the special effort was put into a compilation of a full list of atomic and molecular lines close to the ^{7}Li 6707 Å line (Mishenina & Tsymbal, 1997). The O abundances by the synyhetic spectrum method were determined on [OI] 6300.3 Å line, the Ni I line and the CN lines were included in the final line list. For example, the total uncertainty due to parameters and EW errors for Fe I, Fe II, Si I and Ni I lines is 0.10, 0.12, 0.05, 0.09. correspondly.

6. Results and discussion

As we have not greater number of spectral observation for each spotted star, received during one period of a star, we cannot investigate temperature and an area of spots. But it is not the purpose of our work. Our target stars have given to us as an opportunity to consider behaviour of the elements' abundances with metallicity of the MS and spotted stars. As well as the Sun also belongs to BY Dra type stars it seems interesting to consider separately the behaviour of refractory and volatile elements. The behaviour of these elements is the key in testing one of hypotheses for detection of stars with planetary systems. There are two hypotheses which are based on the study of the chemical composition: 1) primordial scenario, reflects of the high metal content of the protoplanetary cloud from which stars and planets were formed (Santos et al., 2000), 2) different behavior of refractory (Si, Ca, Ti, Sc, V, Cr, Mn, Co, Ni) and volatile (C, S, Zn, N, O, Na, Al, Mg) elements derives from the accretion of a large amount of rocky planetesimal material on to the stars (Gonzales, 1997). Let's note, that in the paper

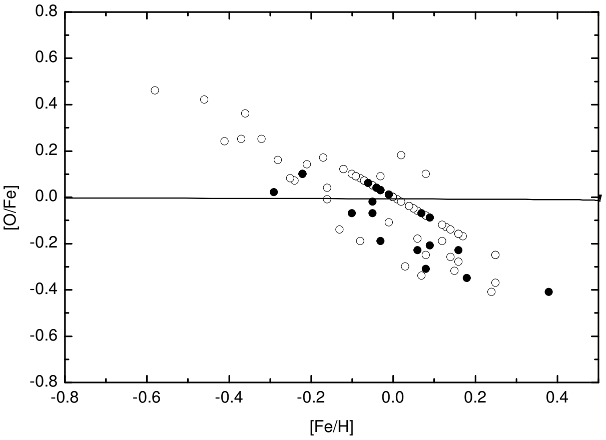

Figure 5: The trend of oxygen with [Fe/H], the notation is the same as in Fig.1.

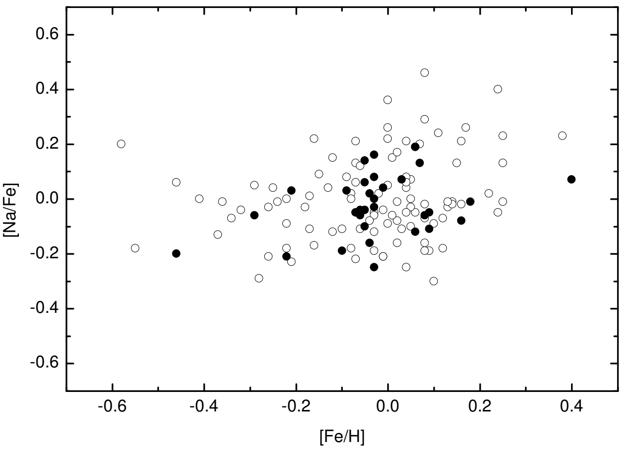

Figure 6: The trend of sodium with [Fe/H], the notation is the same as in Fig.1.

on studying the refractory elements' abundances (Gilli et al., 2006) for single stars and the stars with extrasolar planets the similar trends for these two groups were found. Also in the paper on the oxygen determination (it is one of volatile elements) (Ecuvillon et al., 2006) the appreciable trends distinction for these two groups of stars is not revealed. To analyse behaviour of the elemental abundances we have considered dependences of various element abundances on metallicity. Trends of the studied elements with [Fe/H] presented in Figs.5-13 , where MS stars are marked by open circles, and variable stars are designated by black circles.

We have calculated also the mean abundance values of different elements in the MS and spotty stars (Tabl.1).

As can see from Figs. 5-13 the abundance behaviour of the majority of elemental abundances in MS and spotted stars does not differ. Trend of the elemental abundance corresponds to the received earlier results

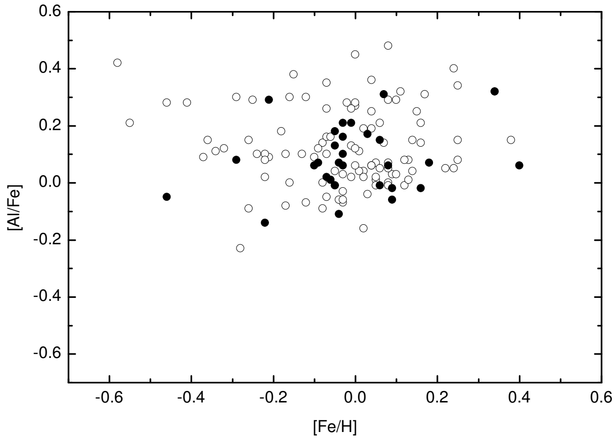

Figure 7: The trend of aluminium with [Fe/H], the notation is the same as in Fig.1.

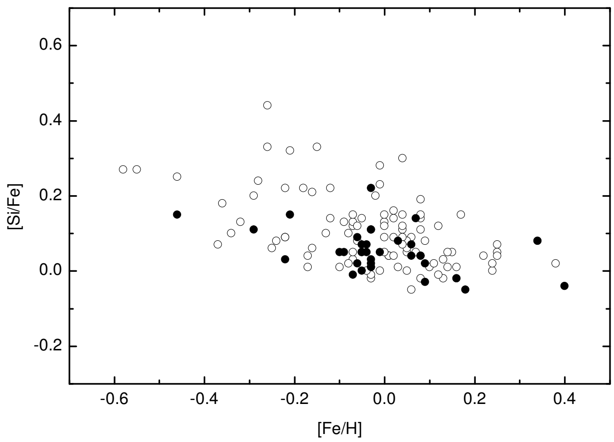

Figure 8: The trend of silicon with [Fe/H], the notation is the same as in Fig.1.

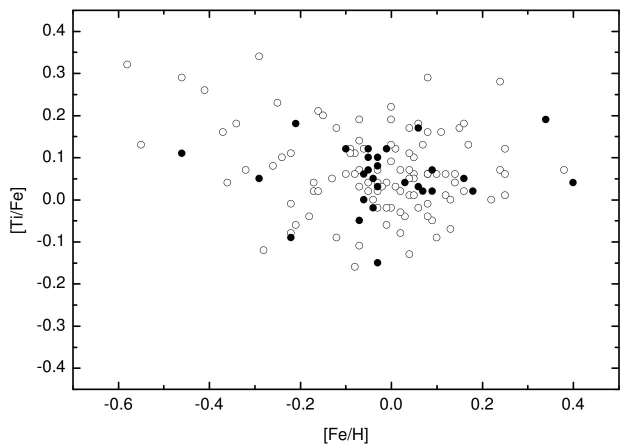

Figure 9: The trend of titan with [Fe/H], the notation is the same as in Fig.1.

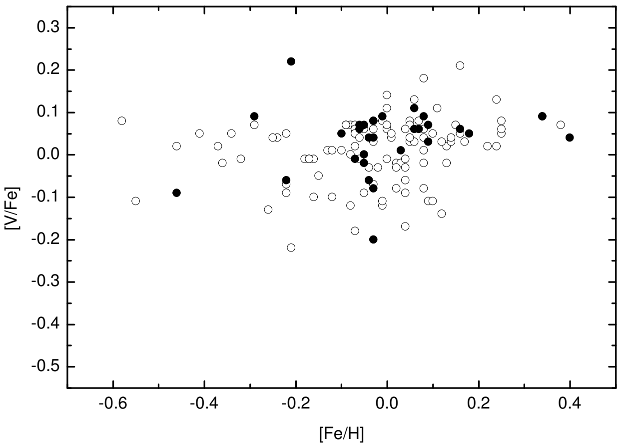

Figure 10: The trend of vanadium with [Fe/H], the notation is the same as in Fig.1.

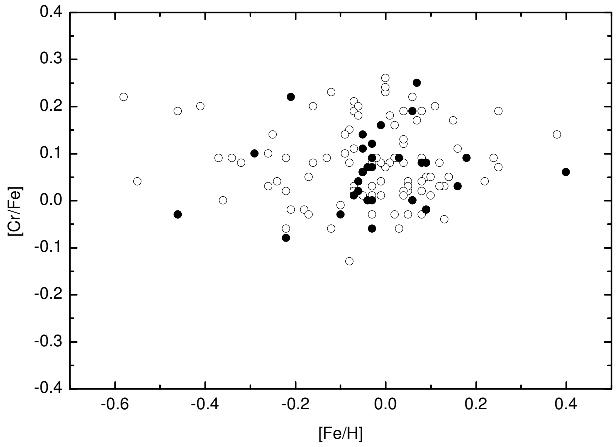

Figure 11: The trend of chromium with [Fe/H], the notation is the same as in Fig.1.

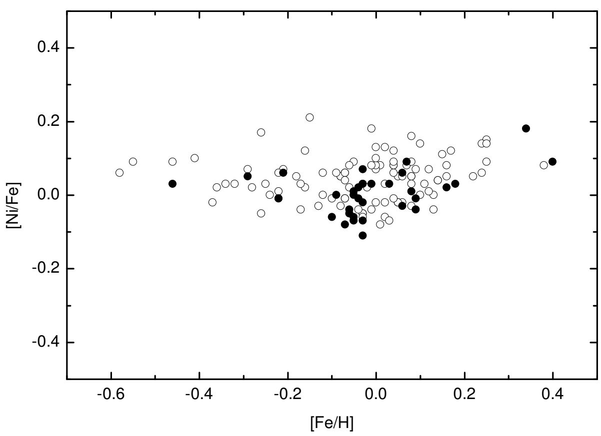

Figure 12: The trend of nikel with [Fe/H], the notation is the same as in Fig.1.

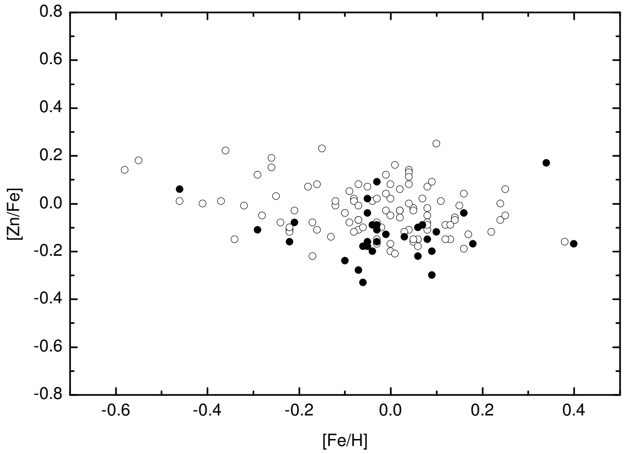

Figure 13: The trend of zinc with [Fe/H], the notation is the same as in Fig.1.

Table 1: The mean values of the elemetal abundance in MS stars [EL/Fe] and in variable stars $[El/Fe]_V$.

Element	$<[El/Fe]>$	σ	N
$<[O/Fe]>$	-0.01	0.18	71
$<[O/Fe]_V>$	-0.11	0.15	18
$<[Na/Fe]>$	0.002	0.15	101
$<[Na/Fe]_V>$	-0.025	0.11	32
$<[Al/Fe]>$	0.12	0.14	101
$<[Al/Fe]_V>$	0.076	0.11	32
$<[Si/Fe]>$	0.102	0.09	101
$<[Si/Fe]_V>$	0.05	0.06	32
$<[Ti/Fe]>$	0.07	0.10	101
$<[Ti/Fe]_V>$	0.05	0.07	32
$<[V/Fe]>$	0.01	0.08	99
$<[V/Fe]_V>$	0.03	0.08	31
$<[Cr/Fe]_V>$	0.06	0.08	31
$<[Cr/Fe]>$	0.07	0.08	99
$<[Ni/Fe]>$	0.04	0.06	101
$<[Ni/Fe]_V>$	0.00	0.06	32
$<[Zn/Fe]>$	–0.025	0.10	99
$<[Zn/Fe]_V>$	–0.12	0.11	31

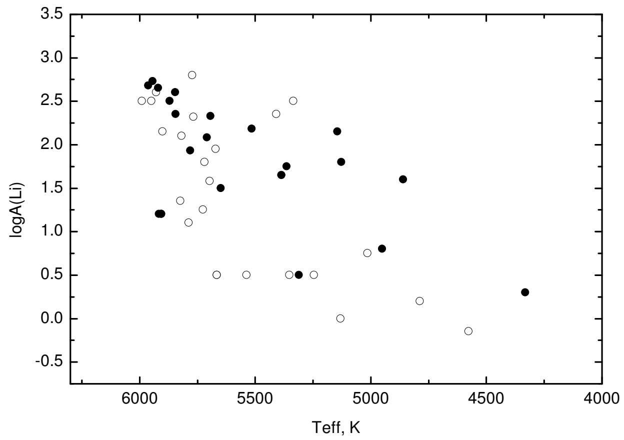

Figure 14: The dependence of Li abundance on T_{eff}, the notation is the same as in Fig.1.

and it is in consent with the galactic chemical evolution. The mean abundance values for MS dwarfs and spotted stars are differ within the limits of definition errors (Tabl.1).

And now we shall consider the lithium abundances in investigated stars. Tracing Li in different types of stellar and sub-stellar objects helps to study physical conditions and nuclear processes in their interia. Li is a very fragile element, destroyed at the temperatures hotter than 2.5 10^6 K, and this process begins already in the pre-main sequence stage. In most general case, the surface abundance of Li should in principle be a function of stellar mass, age, metallicity and to of somewhat poorly explored physical processes like rotation,convection, stellar wind, etc. Stars of BY Dra type belong to young stars, their age is about 10^8 years by estimations of Chugainov (1990). In their spectra the lines of lithium which is the indicator of activity and age of stars are often observed. However these lines have different intensity, sometimes they are absent at all, and their intensity are not always correlates with other indicators of stellar activity. The obtained lithium abundances log A(Li) for investigated stars in functions of effective temperature T_{eff} are presented in Fig.14 where MS stars are marked by black circles, and variable stars are marked by the open circles.

The mean value of Li abundance in the BY Dra type stars is equal to 1.82 $\pm$0.81 and is higher than one (1.42 $\pm$0.91) for MS dwarfs. Lithium is detected in 26 stars from 100 MS dwarfs and in 22 from 33 stars of BY Dra type that there correspond 26 % and 65 %, respectively. Our detailed spectroscopic research of the stars belonging to the low part of MS has shown that the lithium is detected more often in the BY Dra type stars and its average abundance in these stars is higher than in other MS stars.

7. Conclusion

For the first time the chemical composition of about 30 BY Dra type stars was found and the comparison of the lithium abundance in MS stars and of BY Dra type stars was made. There are obtained:

1. Trend of the elemental abundance corresponds to the received earlier results and it is in consent with the galactic chemical evolution.
2. The behaviour of the abundance of the majority elements in MS stars and spotted does not differ.
3. The Li abundance in variable stars is higher than in MS dwarfs and Li is detected in 65 % BY Dra stars and in 26 % of other ones.

References

Alekseev I.Yu.: 2006, *Astrofizika*, **49**, 303.

Alekseev I.Yu., Gershberg R.E.: 1996, *Astrofizika*, **39** 67.

Alekseev I.Yu., Kozhevnikova A.V.: 2005, *Astrofizika*, **48**, 535.

Chugainov P.F.: 1966, *Inform. Bull. Var. Stars.*, 122.

Chugainov P.F.: 1990, Angular Momentum Evolution of Young Stars. Proceedings of the NATO Workshop,Sicily, Italy, Sept. 17-21, 1990. Editors, S. Catalano, J.R. Stauffer: 1991, P.175

Ecuvillon A., Israelian G., Santos N.C. et al.: 2006, *A&A*,**445**, 663.

ESA, 1997, The HIPPARCOS and TYCHO catalogues. Noordwijk, Netherlands: ESA Publications Division, 1997

Galazutdinov G.A.: 1992, Preprint SAO RAS, N 92

Gershberg R.E., Solar type activity of Main Sequence stars: 2002, Astroprint, Odessa.

Gilli G., Israelian G., Ecuvillon A. et al.: 2006, *A&A*,**449**, 723.

Gonzales G.: 1997, *MNRAS*, **285**, 403.

Flower P.J.: 1996, *ApJ*, **469**, 355.

Katz, D., Soubiran, C., Cayrel, R., Adda, M. & Cautain, R.: 1998, *A&A*, **338**, 151.

Kovtyukh V.V., Andrievsky S.M.: 1999, *A&A*, **351**, 597.

Kurucz R.L.: 1993, CD ROM n13

Mishenina T.V., Tsymbal V.V.: 1997, *Pis'ma v Astron. Zhurn.*, **23**, 693.

Santos N.C., Israelian G., Mayor M.: 2000, *A&A*,**363**, 228.

Tsymbal V.V.: 1996 *ASP Conf. Ser.*, **108**, 198.