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Li abundance in the stars with solar-type activity

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Abstract. Li abundances, atmospheric parameters and rotational velocities for 150 dwarfs have been determined from the high resolution, high signal to noise echelle spectra, obtained with the ELODIE spectrograph at the OHP (France). Among them, there are 101 stars with a determined level of activity, a large part of them being of the BY Dra type. The level of chromospheric and coronal activity of the targets has been evaluated through the $\log R'_{\rm HK}$ index and X-ray flux. We examined the Li abundance behavior with $T_{\rm eff}$, $v\sin i$ and level of the activity. Some correlations between the Li abundances, level of the chromospheric activity and rotational velocities $v\sin i$are confirmed. The correlation between the Li abundances and index of the chromospheric activity $\log R'_{\rm HK}$ was found, especially for dwarfs with 5700>$T_{\rm eff}$> 5200 K. Those correlations mainly demonstrate that measurable values of the lithium content (higher than the upper limit) refer to the stars with large spot areas in their photospheres. Considering the wider set of stars with high activity levels one can affirm that such a conclusion is valid also for the cooler, earlier K dwarfs. Our results confirm that basic factors of formation of detectable Li abundance and high activity are determined principally by smaller age and fast axial rotation, respectively; and apparently by the depth of the convective zone.

Key words. Stars: late type – Stars: fundamental parameters – Stars: abundances – Stars: rotation – Stars: activity

1. Introduction

Lithium is an element that plays an important role in testing the theories of the origin of the Universe, galaxies and elements themselves. A large number of mechanisms, operating both inside a star and on the surface, lead to a change in the lithium content in the stellar

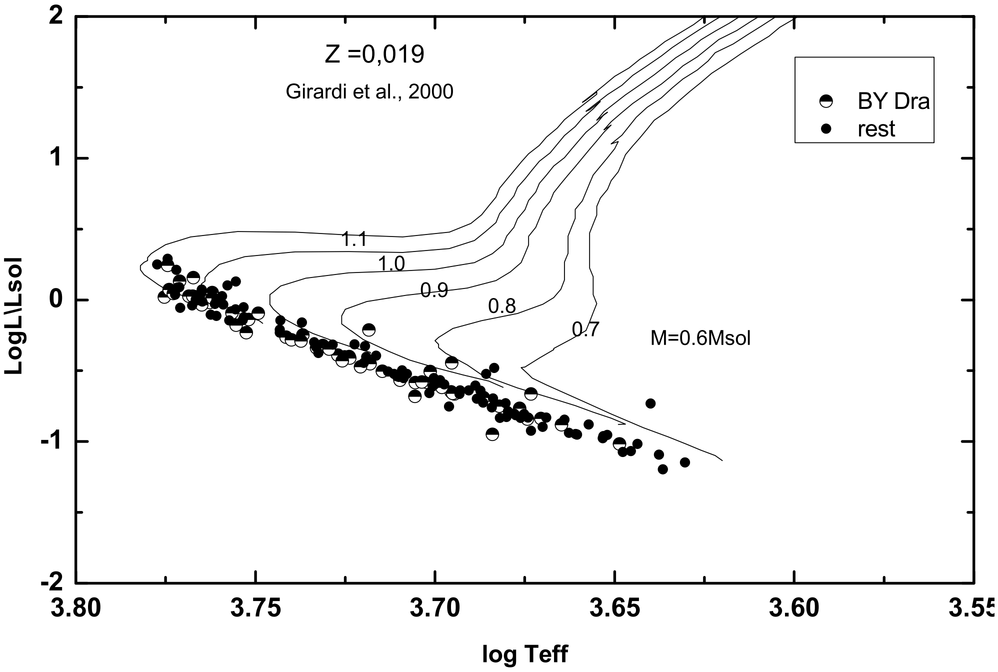

Fig. 1. The position of our target stars at log L/L⊙ vs log$T_{\rm eff}$, the tracks are taken from Girardi et al. (2000), the BY Dra type stars are marked as semi-full circles, and the other stars – as small full circles.

atmosphere. The pattern of the lithium depletion has been intensively studied for the field and open cluster dwarf stars with the near-solar metallicities, but it is still not clearly interpreted. In a standard stellar model for the low-massive stars (0.6–1.2 M⊙), Li is destroyed when the convective envelope reaches the inner layers (Iben 1965). That occurs at the pre-main sequence (MS) stage, continues in the stars at the MS with $T_{\rm eff}$< 5500 K and leads to the lithium depletion in those stars, but not in hotter ones. The Li destruction is more efficient for higher ratio [Fe/H]. Generally, the surface lithium abundance depends on the mass, chemical composition and age (D'Antona & Mazzitelli 1984, 1997).

The activity of stars could also affect the Li abundances "when the extreme energetic conditions are met" (Mullan & Linsky 1999). The fresh isotopes of Li in the solar and stellar atmospheres can be produced also by nuclear interactions of ions accelerated during flares (e.g. see Canal et al. 1975, Livshits 1997, Tatischeff & Thibaud 2007). Only one observational result that corroborates the lithium growth in the stellar flare was obtained by Montes & Ramsey (1998). The question on the connection of the lithium enrichment and stellar activity, especially the magnetic field, remains open for the stars with the solar-type (strong and weak) activity with flares and spots.

2. Observations and determination of parameters

Observations of 150 stars have been carried out with the 1.93 m telescope at OHP (France) equipped with the ELODIE echelle-spectrograph (Baranne et al. 1996). The spectra cover the wavelength range of 440-680 nm at a resolution of 42000, with typical S/N at 550 nm of 100 to 350. The spectra were processed following Katz et al. (1998) and Galazutdinov (1992).

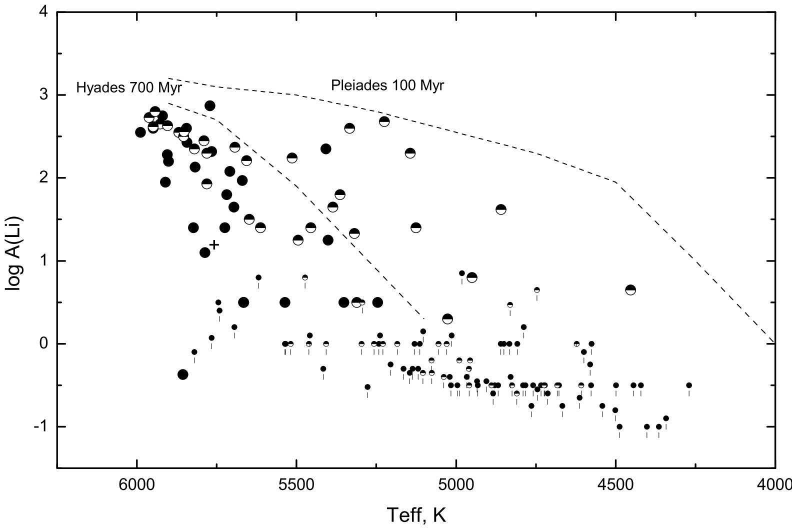

Fig. 2. The Li abundances vs $T_{\rm eff}$, the BY Dra type stars are marked as semi-full circles, the active stars with $\log R'_{\rm HK} > -4.75$ are marked as full circles, the stars with upper limit of the lithium determination — as small symbols. The medium trend of the Pleiades and the Hyades is represented according to Soderblom et al. (1993) and Thorburn et al. (1993), respectively.

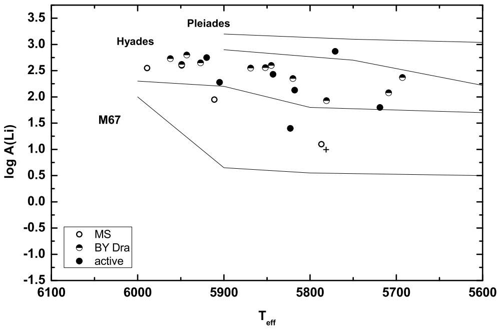

Fig. 3. The dependence of the Li abundance on $T_{\rm eff}$ for the solar-type stars with $6000 > T_{\rm eff} > 5700$, [Fe/H]= 0.0–0.1. The Sun is marked as the cross. The M 67 upper and lower limits are represented according to Pasquini et al. (2008). For the Hyades from (Thorburn et al. 1993) and the Pleiades (Soderblom et al. 1993). Star HD 224465 with the upper limit of the Li determination (<0.5) is not shown due to its binarity. Open circles are MS stars, filled circles – active stars with $\log R'_{\rm HK} > -4.75$, semi-filled cicles – the BY Dra stars.

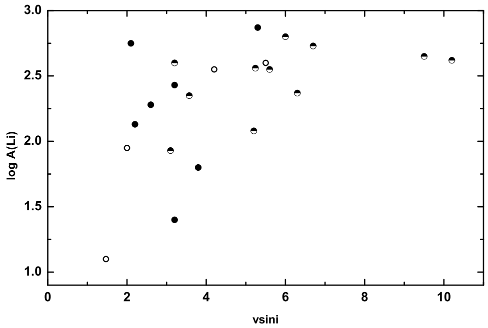

Fig. 4. The Li abundances vs. $v\sin i$. The notation is the same as in Fig.3.

3. Results and conclusions

The rotational velocities $v\sin i$ were determined by calibration of the cross-correlation function (Queloz et al. 1998). The effective temperatures $T_{\rm eff}$ were estimated by the line depth ratio method. The surface gravities log g were computed by two methods: the iron ionization balance and the parallax. Determination of the

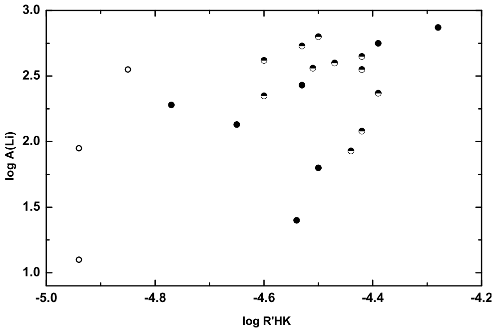

Fig. 5. The Li abundances vs. $\log R'_{\rm HK}$. The notation is the same as in Fig.3.

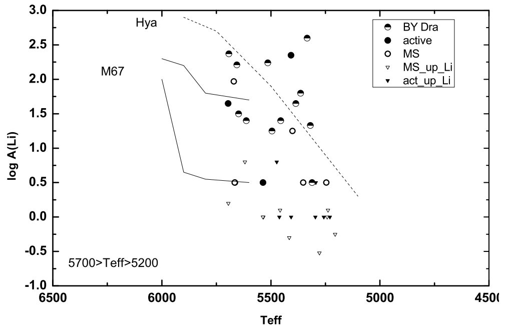

Fig. 6. The dependence of Li abundance on $T_{\rm eff}$ for the stars with 5700>$T_{\rm eff}$>5200. The BY Dra type stars are marked as semi-full circles, the active stars with $\log R'_{\rm HK}$ > -4.75 are marked as full circles, the MS stars – as open circles, the stars with upper limit of the lithium determination – as small symbols.

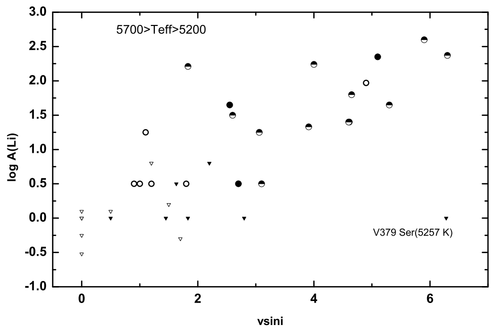

Fig. 7. The dependance of Li abundance on $v\sin i$ for the stars with 5700>$T_{\rm eff}$>5200, the notation is the same as in Fig.6.

Li abundance was made by the STARSP LTE spectral synthesis code (Tsymbal 1996), using the models of Kurucz (1993). The parameters ($T_{\rm eff}$, log g, V_t, [Fe/H]) and the Li abundances are determined for 150 stars; among those there are 100 stars with the determined level of activity, and a large part of them are the BY Dra type stars. The level of the chromospheric and coronal activity of the target stars was evaluated through $\log R'_{\rm HK}$ index (as basis, Wright et al. 2004) and the X-ray flux from the ROSAT All-Sky Survey (Voges et al. 1999). For several stars, the levels of chromospheric and coronal activity were estimated from other observations or by indirect methods. The active stars of BY Dra type were taken from SIMBAD; a part of the rest of the stars with the value of $\log R'_{\rm HK}$>–4.75 were also adopted as the active stars, and the other stars were considered as inactive ones. The position of the investigated stars in coordinates log L/L⊙ vs. log $T_{\rm eff}$ and the evolution tracks by Girardi et al. (2000), where log L/L⊙= 0.4(4.79–Mv), are presented in Fig. 1. The behaviour of the Li abundance was examined in correlation with $T_{\rm eff}$, vsini and the level of activity $\log R'_{\rm HK}$. For all studied stars, the obtained lithium abundances log A(Li) vs. the effective temperature $T_{\rm eff}$ (Fig.2) show typical (evolutionary) decrease of the Li content with decreasing $T_{\rm eff}$, and also with a rather large dispersion that corresponds to different ages of the studied stars according to the "trends" of the open clusters. Then, we divide our stars into three groups with different temperatures, and examined the dependence of the lithium content on the various parameters (Figs.3–10).

At Fig.10, for stars with $T_{\rm eff}$<5200, we see the known stars of the BY Dra type that are binary stars: V833 Tau, V834 Tau, V379 Ser, BY Dra, OU Gem, V775 Her. As can be seen from the figures, dependences of log A(Li) abundance vs. parameters for the stars with 5700>$T_{\rm eff}$>5200 are expressed more clearly than for other stars. The stars of our sample where lithium was registered. Three figures for the stars with 5700>$T_{\rm eff}$>5200 indicate real connection of the activity level with

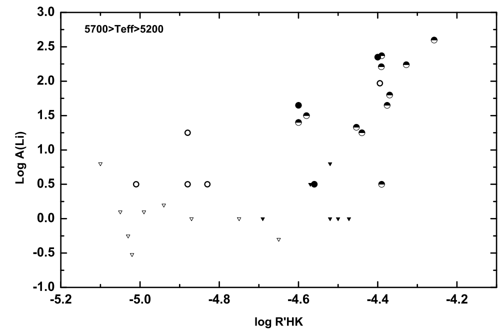

Fig. 8. The dependance of Li abundance on $\log R'_{\rm HK}$ for the stars with $5700>T_{\rm eff}>5200$, the notation is the same as in Fig.6.

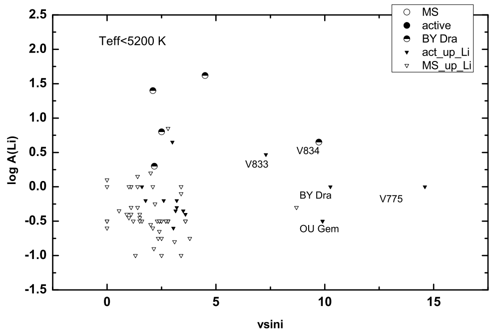

Fig. 10. The dependance of Li abundance on $v\sin i$ for stars with $T_{\rm eff}$<5200 K. The notation is the same as in Fig.6.

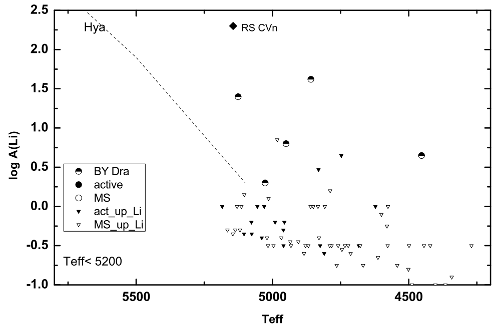

Fig. 9. The dependance of Li abundance on $T_{\rm eff}$ for stars with $T_{\rm eff}$<5200 K. The notation is the same as in Fig.6.

the lithium in the photosphere. The dependence of the lithium abundance on the rotation velocity is much better expressed for those stars, and less for the hot ones and, for cool stars. For the stars with $5700>T_{\rm eff}>5200$, we can directly conclude that there is a correlation between the lithium abundance and the chromospheric activity.

However, if we extend the sample of K stars with detectable lithium (Maldonado et al. 2010), then, those relationships remain true both for G and earlier K stars. Such active G and K stars including the part of the BY Dra-type stars are characterized indeed by the pronounced rotational modulation in the optical continuum, as pointed out by Messina et al. (2003); that is due to the presence of spots on the surface and one can expect strengthening of the lithium line.

There are several mechanisms of appearance of lithium in the stellar atmosphere. Actually, we obtained the evidence in favor of the lithium connection to the spots. If those stars rotate rapidly, they are a group of stars with the chromospheric activity, whose age is much more than the age of the young open clusters. Those stars were identified in a separate group in the work of Rocha-Pinto et al. (2002).

4. Discussion

Let us consider briefly those results in the context of wider study of solar-type activity of stars. The other samples of active late-type stars including objects investigated during the HK Project and Exoplanet Search Programs were analyzed together with the available X-ray data by Katsova and Livshits (2011 and Table therein). For 171 stars and the Sun the "chromosphere – corona" diagram is constructed (Fig. 11), and there is the correlation between chromospheric and coronal activity. The result of the previous consideration by Mamajek & Hillenbrand (2008) of other samples of stars is presented with the straight line in Fig.11. This correlation was a base for estimate of the age from the level of chromospheric activity (gyrochronology). Note that addition of the stars from the planet search pro-

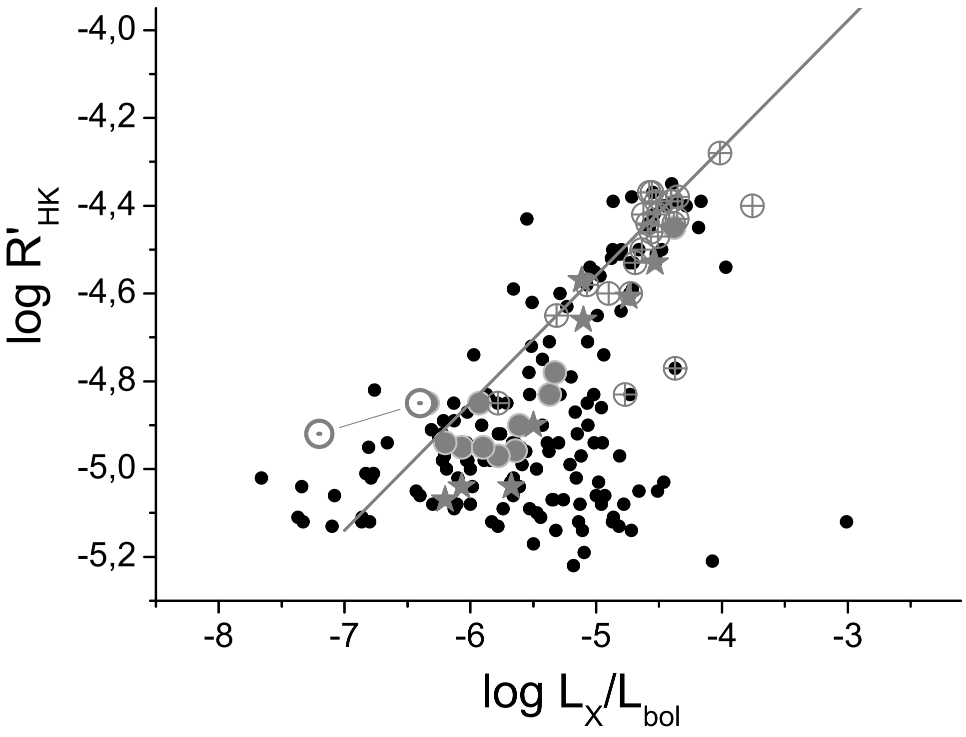

Fig. 11. The comparison of indices of chromospheric and coronal activity of late-type stars. The stars of the basic data set (Table in Katsova & Livshits (2011)) are marked as dots. The HK Project stars with Excellent cycles are marked with filled circles, and those with Good cycles with asterisks. The solar symbol is used for the Sun; the values at the maximum and minimum of the solar cycle are connected. The investigated stars with measured lithium abundance and with direct measurements of $\log R'_{HK}$ indices (from the studies mentioned above) are marked as crosses inside the circles. The straight line corresponds to the linear regression by Mamajek & Hillenbrand (2008) (see text).

grams allows us to reveal a significant group of the stars below this line. This shows that such a one-parameter gyrochronology can not be applied for all the late-type stars. Further we add a set of above investigated stars with registered Li I 6707 Å line and measured chromospheric activity indices.

In Fig.11 it is seen that the stars with heavy lithium are characterized by high activity level. Those stars with lithium fill up the area, corresponding to the transition from the stars with the solar-like activity to the objects with saturated activity levels. The stars with saturation of activity were studied in details by Martínez-Arnáiz et al. (2011). Those authors found that K stars on the H-alpha radiation fluxes are divided into two kinds related to the common and saturated levels.

The above described results allowed us to consider how does evolve the solar-type activity (Katsova 2012). Indeed, in Fig.11 several stars with detected Li also deviate downwards the linear dependence. Both stars with detectable lithium and those with weak chromospheres and strong coronae demonstrate deviation from the straight line (one-parameter gyrochronology) that apparently can mean that there is another way for the evolution of solar-type activity beside this main path. Namely, starting from a definite activity level of many late G and K stars, the chromospheres become weaken while coronae stay still powerful. Both paths shown conditionally in Fig.4 in Katsova (2012) can be considered as envelopes for all possible ways for the evolution of solar-like activity depending on masses and individual parameters. When a young star brakes down, the chromospheric and the coronal activity weaken synchronously. The solar-like activity of the most main sequence F and early G stars can evolve by this path. The activity of the later stars from G5 to K7 after a definite level evolves by another way: the chromospheric activity diminishes up to the solar level, while coronae stay stronger than the solar one. This occurs due to action of the two-level dynamo mechanism when large-scale magnetic fields occur near the lower bottom of the convective zone, whereas local fields are formed at relatively shallow depths beneath the photosphere.

Note that the depth of the convective zone can affect also on the diffusion of the atoms of lithium. When the lower boundary of the convection zone of low-mass stars later than G7 locates at levels with the plasma temperatures more 1–3 millions K, the primordial lithium destroys, and its abundance in the photosphere decreases. As for stellar activity, quasi-stationary and non-stationary processes like spots, sub-flares etc, provide the high level of the coronal activity when these stars are fast rotators. Thus, both problems discussed here, the lithium abundance and the activity level, are associated not only through rotation but also the depth of the convection zone. Because both these factors act in different directions, we find the higher lithium abundance not exactly for the stars with high activity levels. Namely this fact can explain differences in the spectral types stars with lithium detection and strongly spotted stars with high amplitudes of the rotational modulation in the optical continuum.

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