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Solar twins: lithium abundance scatter

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Abstract. To clarify the reasons for the dispersion of Li in the atmosphere of solar type stars, a set of 56 solar analogs including 22 solar twins is analysed based on spectra obtained with the ELODIE spectrograph at Observatoire de Haute Provence (France). Lithium abundances are derived by comparing observed and synthetic spectra in the region of Li I line 6707 Å in LTE approximation. The dependencies of the Li abundances on effective temperature Teff, age, rotational velocities vsini and chromospheric activity log R'HK were constructed and analyzed in the frame of stellar evolution theories. The results obtained are generally consistent with theories considering induced-rotational mixing.

Key words. Stars: abundances – Stars: evolution – Stars: solar-type

1. Introduction

Li is a fragile element that can be destroyed by nuclear reactions at temperatures in excess of 2.5×10^6 K. This property leads to large variations in its abundance. Why is there some scatter of lithium abundance in solar analogs? With our spectroscopic analysis we want to investigate the (hidden) processes that lead to lithium depletion and understand whether they happen during the gravitational contraction of protostellar cloud, during the evolution on the stage Pre- Main Sequence (MS) or during MS.

The possible sources at Pre-MS may be:

1) episodic accretion, pre-MS core-envelope decoupling and/or radius inflation due to enhanced magnetic activity to account for an early development of the Li-rotation connection (Bouvier et al. 2016);
2) planet accretion (Montalban & Rebolo 2002), (Baumann et al. 2010);
3) metal-rich accretion and thermohaline instability (Théado & Vauclair 2001);
4) the impact of starspots on the evolution of late-type stars (Somers & Pinsonneault 2016);
5) different physical conditions, primarily during the early stage of evolution before the MS (Thévenin et al. 2017);

At MS the possible sources may be:

1) atomic diffusion (Michaud 1986),
2) mass loss (Hobbs, Iben & Pilachowski 1989),

3) magnetic braking of solar rotation (Denissenkov 2010),
4) rotationally-induced mixing and atomic diffusion (Chaboyer, Demarque & Pinsonneault 1995), (Talon & Charbonnel 2005), (Do Nascimento et al. 2009) etc.,
5) overshooting, extra-mixing at the bottom of a convective zone (Baraffe et al. 2017),
6) rotation-induced mixing and internal gravity waves (Charbonnel & Talon 2005),
7) large starspots and superflares (Notsu et al. 2017),
8) presence planetary systems (Gonzalez & Laws 2000), (Delgado Mena et al. 2015), (Mishenina et al. 2016), (Carlos et al. 2016) etc.

Other important factor in Li abundance changing was considered by Somers & Pinsonneault (2014): uncertainties in the standard physics, adopted equation of state and solar composition; the very high temperature sensitivity of the Li depletion.

2. Observations, stellar parameters and Li abundance determination

The spectra were taken from the archive of the ELODIE echelle spectrograph on the 1.93m telescope of OHP (France), a resolving power of R≃42 000 and the wavelengths range 4400–6800 ÅÅ (Moultaka et al. 2004).

To select solar twins, the 225 best spectra of 56 stars were analysed by Mahdi et al. (2016) and twenty-two stars were found to differ by less than 100 K in Teff, 0.1 dex in log g, and 0.1 dex in metallicity from the Sun values, which correspond to the definition of solar twins by Melendez et al. (2014).

The atmospheric parameters and abundances from (Mahdi et al. 2016) were used. The abundance of the Li was determined based on the synthetic calculation of LiI line of 6707 Å under LTE approximations using the atmosphere models by Castelli & Kurucz (2004), new version LTE STARSP software package (Tsymbal 1996) and the VALD atomic data (Kupka et al. 1999). The NLTE corrections in our case are from 0.04 to 0.07 dex (Lind, Asplund & Barklem 2009). This is within the limit of definition errors. We determined rotation velocity vsini with the relation calibrated by Queloz et al. (1998). The parameter of chromospheric activity log R'HK was taken from Wright et al. (2004). The ages were determined using the [Y/Mg] calibration (Tucci Maia et al. 2016).

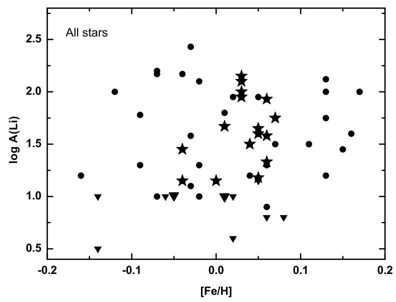

Fig. 1. Li abundance vs. [Fe/H] in our target stars. For solar twins, the lithium content is indicated as asterisks, the upper limit of log A(Li) as large triangles.

3. Result and discussion

To analyze the behavior of lithium in solar twins, we have plotted the dependences of Li abundance log A(Li) on [Fe/H] (Fig. 1), Teff (Fig. 2), the rotation velocity vsini (Fig. 3), age (Fig. 4), and parameter of chromospheric activity log R'HK (Fig. 5), and also the dependence of chromospheric activity log R'HK on vsini (Fig. 6).

The connection of Li abundance with vsini may be the result of the past rotational history of stars (Bouvier et al. 2016); or that the fact that fast rotators appear to be less depleted than their slow rotating counterparts (Baraffe et al. 2017); and also that the stars have different initial velocities (Charbonnel & Talon 2005). Correlations between log A(Li) and log R'HK with vsini for solar twins suggest that the rotation is a crucial factor in the physical processes that are responsible for the values of the Li abundance and the levels of chromospheric activity. In Figs. 7,and 8 we compare our Li determinations for solar twins with calculations

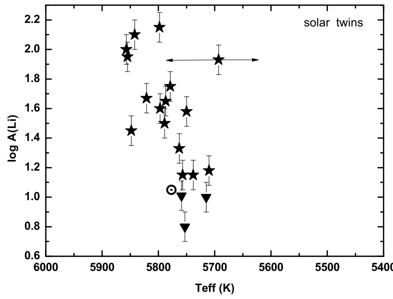

Fig. 2. Li abundances as a function of Teff for solar twins. Li abundances range from 0.8 to 2.2dex.

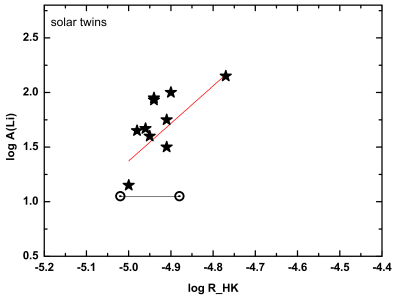

Fig. 5. Li abundance as a function of chromospheric activity log R'HK for solar twins.

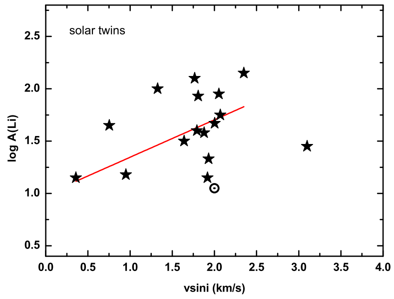

Fig. 3. Li abundance vs. vsini for solar twins.

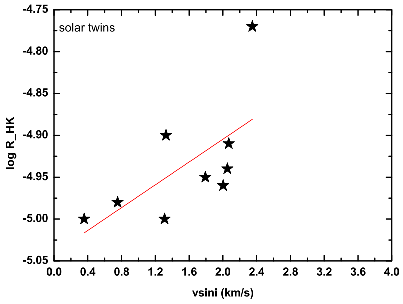

Fig. 6. Chromospheric activity log R'HK as a function of vsini for solar twins.

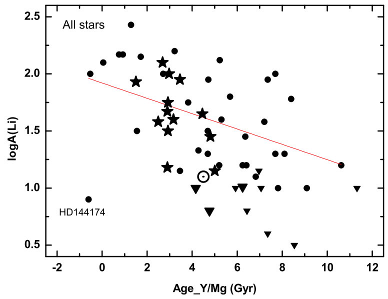

Fig. 4. Li abundance vs. age for our target stars. Notation is the same as Fig. 1.

of Baraffe et al. (2017) and also Charbonnel & Talon (2005), that consider a rotation-induced mixing and internal gravity waves (IGWs) as main source of depletion of Li. We can see a good agreement between Li abundance and two stellar evolution computations especially of (Charbonnel & Talon 2005).

4. Conclusions

– Li abundances were determined in carefully selected solar analogs including solar twins and analyzed against on various parameters. We find a correlation of Li abundance with Teff, vsini, age and on chromospheric activity logR'HK. – The comparison of our observational data with some calculations of the Li evolution in solar twins was made. The decisive factor in lithium dispersion in the stars of the MS is the initial spread of the rotational velocities. However, one should not exclude the in influence of other factors (magnetic activity, meridional circulation, diffusion, etc.).

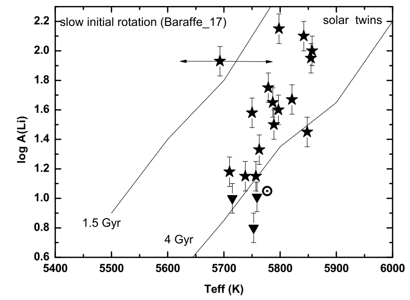

Fig. 7. Li abundance vs. Teff for solar twins and model calculation of Baraffe et al. (2017).

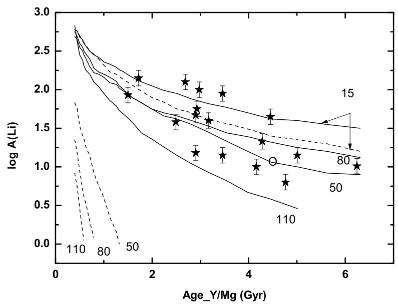

Fig. 8. Li abundance vs. Age for solar twins and model calculation of Charbonnel & Talon (2005). Solid lines correspond to models including IGWs and dashed lines to models without IGWs. Initial velocities are shown in kms^{-1}. The solar value is shown as circle.

– The observed scatter in Li abundance of solar twins is in good agreement with predictions of models considering rotation-induced mixing and internal gravity waves (Charbonnel & Talon 2005).

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