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Lithium and age of pre-main sequence stars: the case of Parenago 1802

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Abstract. With the aim to test the present capability of the stellar surface lithium abundance in providing an estimation for the age of PMS stars, we analyze the case of the detached, double-lined, eclipsing binary system PAR 1802. For this system, the lithium age has been compared with the theoretical one, as estimated by applying a Bayesian analysis method on a large grid of stellar evolutionary models. The models have been computed for several values of chemical composition and mixing length, by means of the code FRANEC updated with the Trojan Horse reaction rates involving lithium burning.

1. Introduction

Among the observational parameters, surface lithium abundance is definitely of interest for Pre-Main Sequence (PMS) late-type stars, which have deep convective envelopes. As a consequence of the PMS contraction, their interior heats up and when the temperature at the base of the convective zone, T_{BCZ}, reachs that of Li burning, $T_{LB} \sim 2.5\times10^6$ K, lithium is here destroyed via (p,α) reactions. Convection is then responsible for the observed lithium depletion, by bringing the processed material to the stellar surface and the not yet processed one to the inner regions. The efficiency of this process strongly depends on stellar metallicity (mass fractional abundance of elements heavier than helium) and mass. Li-burning is faster in metal-rich stars, since the higher opacity and the consequent deeper convective envelope results in a higher T_{BCZ}. Moreover, fully convective stars reaching T_{LB} (mass 0.06-0.40 $M_\odot$ for solar metallicity, Tognelli et al. 2015) completely destroy the initial lithium content from few tens to hundreds Myr in dependence on the mass: the smaller the mass, the greater the time to reach T_{LB}, the longer the Li-burning timescale. In the interior of more massive stars (0.40-1.20 $M_\odot$) a radiative core develops and grows up as faster as larger is the mass, so that the convective envelope becomes progressively less extended until $T_{BCZ} < T_{LB}$ and the Li-burning is stopped. Since at fixed mass and chemical composition the depth of the convective envelope is age-dependent, in principle the measured surface lithium abundance of PMS late-type stars can be used to derive the stellar age (*lithium age*), if mass and metallicity are known. However, despite the capability of the current

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stellar models in reproducing the main evolutionary parameters, the still present disagreement between observed and predicted surface lithium content doesn't confirm the validity of this method. Anyway, for PMS stars a better agreement between theory and observations can be obtained, in some cases, just tuning the external convection efficiency (the mixing length parameter), which often results to be lower than the Main Sequence value (Tognelli et al. 2012, hereafter T12).

In this work we have tested the power of the surface lithium abundance to provide an estimation for the age of the PMS, detached, double-lined, eclipsing binary system Parenago 1802 (hereafter PAR 1802), for which surface iron abundance and dynamical masses are available (Table 1).

2. Determination of theoretical and lithium age for PAR 1802

In principle, if we exactly know 1) the metallicity and the mass of a star, 2) a set of observational quantities (e.g. effective temperature, surface gravity, radius) and 3) the observed photospheric lithium abundance, we can a) compute the model with the known values of metallicity and mass, b) within this model, search for the age when the observed parameters (point 2) appear simultaneously (*theoretical age*) and c) independently, search in the model for the age corresponding to the observed lithium abundance (*lithium age*). However, observed parameters (including metallicity and mass) are affected by errors. Therefore, in order to take into account all the uncertainties at the same time, we have applied a Bayesian analysis (Jörgensen and Lindegren 2005) for deriving theoretical estimation of mass (M) and age (τ), by following Gennaro et al. 2012 (hereafter GPT12). The Bayesian Method is a statistical powerful tool which allows to obtain an estimation of stellar parameters (in our case mass and age) by comparing observational evidences of other quantities (in our case effective temperature, surface gravity, radius) with models' predictions for the same quantities, and by taking into account the *a priori* information about metallicity and parameters to be determined, if any. From the resulting model, we have derived the lithium age and compared it with the theoretical one.

We have computed a database of PMS stellar models by means of the Frascati Raphson Newton Evolutionary Code (FRANEC, Degl'Innocenti et al. 2008). Input physics is as in GPT12, limited to the primordial helium abundance Y_p=0.2485 and the helium-to-metal enrichment ratio $\Delta Y/\Delta Z$=2, with the exception of the solar-scaled heavy-element mixture, that is from Asplund et al. (2009). For the initial abundances of ^{6}Li, Be, B we have adopted the values given in Prantzos (2012), while we have set the logarithmic initial ^{7}Li abundance A(^{7}Li)[1]=3.2 (e.g. Jeffries 2000). It has to be noted that the accuracy of theoretical evolutionary models in predicting surface abundance of light elements largely relies on both the adopted mixing length parameter and the nuclear reaction rates. The former can be arbitrarily set in the code as input, e.g. on the basis of considerations related to the evolutionary stage of the star in exam (T12). Regarding to the charged-particle-induced reactions at astrophysical energies (∼keV), the cross sections are underestimated by direct measurements because of the Coulomb barrier (∼MeV) between the interacting ions, and overestimated by low-energy extrapolation procedures on direct measurements made at higher energies because of the electronic screening phenomena due to the electron clouds surrounding the interacting nuclei. The Trojan Horse Method (THM; Baur 1986; Spitaleri et al. 2011) is a powerful indirect technique which allows to measure the bare-nucleus factor at astrophysical energies without invoking both Coulomb penetrability and electron screening effects (see e.g. Tumino et al. 2007). We have adopted nuclear reaction rates from NACRE compilation and JINA REACLIB database, but for the following ones derived with the THM: d(d,p)t and d(d,n)^{3}He (Tumino et al. 2014), ^{6}Li(p,α)^{3}He (Lamia et al. 2013), ^{7}Li(p,α)^{4}He (Lamia et al. 2012). We have obtained models for different metallicities Z: 0.00700,

[1] A(^{7}Li) = 12 + $logN_{Li}/N_H$ where N_{Li} and N_H indicate respectively the lithium and hydrogen numerical abundance.

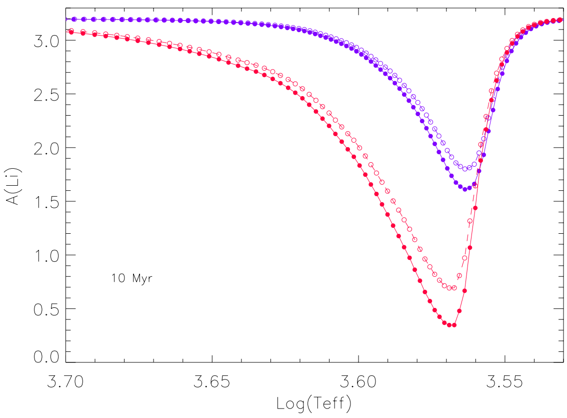

Figure 1. Logarithmic surface ^{7}Li abundance is plotted against T_{eff}, at the same age (10 Myr), for two classes of models with solar metallicity and mixing-length parameter α=1.00 (purple), α=1.74 (red). Each class has been computed with different inputs for cross sections of reaction involving lithium, i.e. empty circles for THM and filled circles for NACRE (Angulo et al.1999).

Table 1. Input stellar parameters for PAR 1802 A: M_{dyn}=0.391±0.032 $M_\odot$, $T_e[K]$= 3675±150, log$g$=3.55±0.04, R=1.73±0.02 $R_\odot$, A(^{7}Li)=1.48±0.21. For B component, in the same order: 0.385±0.032, 3365±150, 3.61±0.04, 1.62±0.02, 0.57±0.22 (Cargile et al. 2008, Gómez Maqueo Chew et al. 2012). [Fe/H]=-0.01±0.04 (D'Orazi et al. 2009). A(^{7}Li) are according to Pavlenko and Magazzú (1996) NLTE computations. Stellar (τ_{star}), system (τ_{sys}) and lithium (τ_{Li}) ages are in Myr.

PAR	α = 1.00				α = 1.74			
1802	M[$M_\odot$]	τ_{star}	τ_{sys}	τ_{Li}	M[$M_\odot$]	τ_{star}	τ_{sys}	τ_{Li}
A	$0.40^{+0.02}_{-0.04}$	$1.05^{+0.11}_{-0.11}$	$1.10^{+0.09}_{-0.08}$	$12.6^{+0.05}_{-0.05}$	$0.39^{+0.04}_{-0.02}$	$0.75^{+0.08}_{-0.07}$	$0.79^{+0.07}_{-0.05}$	$13.0^{+0.05}_{-0.05}$
B	$0.39^{+0.02}_{-0.04}$	$1.16^{+0.13}_{-0.14}$		$12.6^{+0.05}_{-0.05}$	$0.38^{+0.02}_{-0.02}$	$0.85^{+0.08}_{-0.08}$		$13.0^{+0.05}_{-0.05}$

0.00800, 0.00900, 0.01000, 0.01291 (solar value), 0.01550 and 0.01800. For each Z-value, we have computed models with mixing-length α=1.00 (suitable for PMS stars, T12) and α=1.74 (the solar-calibrated value). In order to obtain a high precision in the Bayesian analysis, we have computed a very fine grid of models in the mass range [0.20, 2.50] $M_\odot$ as it follows. The models have initially been obtained with a spacing of 0.25 $M_\odot$. Then we have interpolated the grid with a spacing of 0.0125 $M_\odot$ and 0.005 Myr in the full mass range.
An interesting comparison for surface lithium predicted by models obtained with different inputs is shown in Figure 2.
Physical parameters used in the analysis are in Table 1 together with the Bayesian results.

3. Results and Conclusions

Figure 2 shows Bayesian results for α=1.00 and 1.74. In both cases (Table 1) the theoretical age (∼1 Myr) indicates a system too young to burn lithium, while the lithium age (∼13 Myr) indicates a system with an efficient lithium burning process. As a conclusion from our analysis, differences between theoretical ages and lithium ages, at least in the case of PAR 1802, cannot be ascribed to the mixing length parameter.

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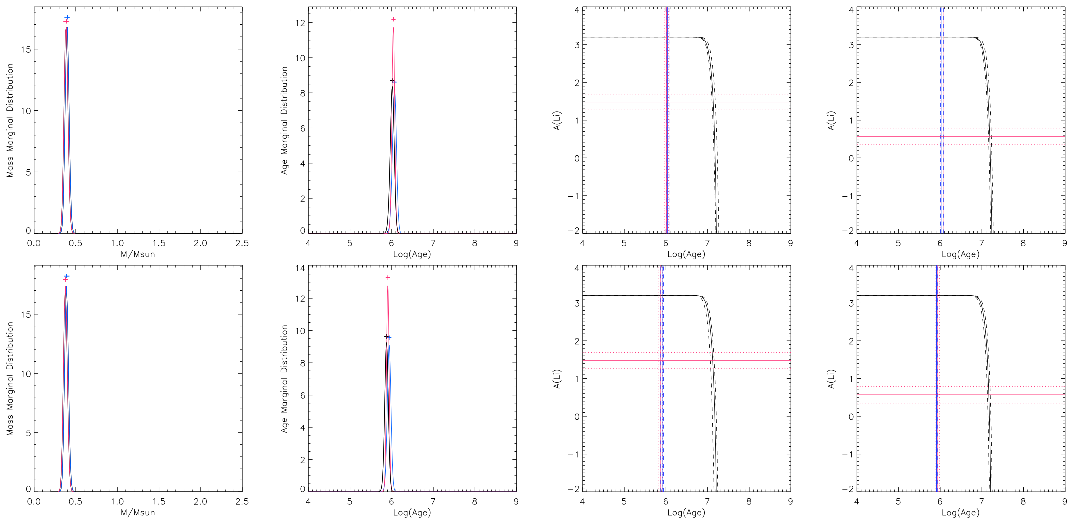

Figure 2. Bayesian results for α=1.00 (top panels) and α=1.74 (bottom panels). From left: mass marginal distribution of primary (blue) and secondary (red) component, age marginal distribution of primary (black), secondary (blue) and system (red), lithium depletion pattern of primary and secondary component in black solid line, dashed the propagation of mass error from confidence interval. Blue vertical solid line marks the bayesian age of the single star, dashed the associated error from the confidence interval. Red vertical solid line marks the system age (coevality), dotted the associated error from the confidence interval. Red horizontal solid line represents the observed lithium abundance, dotted the associated error. Horizontal line in marginal distribution represents the confidence interval.

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