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Lithium evolution in young open clusters from the Gaia-ESO Survey

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Abstract. The Gaia-ESO Survey provides the largest database of homogeneously-determined lithium abundances and stellar parameters for open star clusters of different age and metallicity. It is therefore well suited to investigate young stellar evolution and to provide independent age estimates in young clusters. We present the lithium results for a sample of young clusters of ages between 10 and 100 Myr, and compare the observed lithium depletion patterns with models of lithium depletion in pre-main sequence stars.

Key words. Stars: abundances – Stars: evolution – Stars: late-type – Stars: pre-main sequence

1. Introduction

The Gaia-ESO Survey (GES, Gilmore et al. 2012; Randich et al. 2013) is a large public spectroscopic survey, conducted with the FLAMES instrument at the VLT, which is providing accurate radial velocities and homogeneous stellar parameters and chemical abundances (up to 32 elements, including lithium) for $\sim 115\,000$ stars in all Milky Way components, from the thin and thick disk to the bulge and halo. In particular, the final data release will provide lithium abundances and/or equivalent widths for $\sim 40{,}500$ stars, 80% of which are located in about 80 open clusters of different age and metallicity, ranging from a few Myrs to several Gyrs. GES therefore constitutes the largest database available to date of homogeneously-determined lithium abundances and stellar parameters for open clusters, allowing us to investigate in detail the lithium evolution with age and to put important constraints on stellar evolutionary models.

The GES observations of the young Gamma Vel open cluster (age 10−20 Myr) revealed a peculiar lithium depletion pattern (Jeffries et al. 2014), showing a continuous range of abundances in M-type stars, from nearly undepleted to fully depleted lithium (see Fig. 1). Jeffries et al. (2017) found that standard evolutionary models (Baraffe et al. 2015; Dotter et al. 2008) cannot reproduce this depletion pattern at the same age (~ 7.5 Myr) that fits the colour-magnitude diagram (CMD): the observed strong lithium depletion would in fact require significantly larger ages, and it also occurs at much lower temperatures than the model predictions. However, they also found

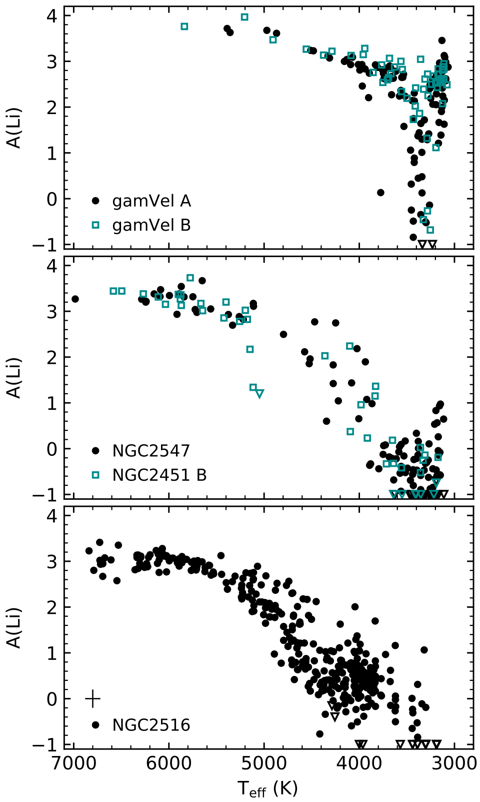

Fig. 1. Evolution of lithium depletion with age: Gamma Vel A and B at ~10−20 Myr (*top*), NGC 2451 B and NGC 2547 at ~35 Myr (*center*), and NGC 2516 at ~100−140 Myr (*bottom*). Downward triangles indicate upper limits. A typical error bar is shown in the bottom panel.

that a radius inflation by ~10%, assuming fully-convective stars with a simple polytropic structure, would be able to reproduce both the CMD and the lithium pattern at an age of ~18−21 Myr.

2. Lithium depletion at 10-100 Myr

The results from Jeffries et al. (2017) motivated us to better investigate the issue of Li depletion in young clusters as a function of age. To this aim, in addition to Gamma Vel, we considered three other clusters observed by GES: NGC 2451 B and NGC 2547, at ~35 Myr (Jeffries & Oliveira 2005; Randich et al. 2018), and NGC 2516, at ~100−140 Myr (Lyra et al. 2006; Randich et al. 2018). For our analysis, we took advantage of the *Gaia* DR2 astrometry which, combined with the GES data, allowed us to obtain clean membership lists, and to extend the cluster sequences at the bright end not covered by the GES observations. The *Gaia* parallaxes also allowed us to derive new accurate distances for the clusters: this is particularly important in the case of Gamma Vel, for which we found that its two kinematically-distinct populations (Gamma Vel A and B) are also separated in distance by ~40 pc (Franciosini et al. 2018).

In Fig. 1 we plot the lithium patterns of the high-probability members ($P > 80\%$) of the four clusters, that clearly show the evolution of lithium depletion with age. The large spread in abundance seen in M-type stars at the age of Gamma Vel has disappeared at 35 Myr, where all M-type stars are strongly or fully depleted, and depletion occurs also at higher masses; the lithium depletion boundary is also clearly visible in NGC 2547. As expected, depletion increases at ~100 Myr, although there is still a fraction of low-mass stars that are not yet fully-depleted.

3. Spotted models

Radius inflation in young, active stars is generally attributed to the effect of magnetic activity, that can alter the stellar structure either by reducing the convection efficiency, or because of the presence of large spots that block the emerging flux (e.g. Chabrier et al. 2007; Feiden & Chaboyer 2012, 2014; Jackson & Jeffries 2014; Somers & Pinsonneault 2015).

In this work, we concentrated our analysis on the effects of spots, using as a basis the PISA evolutionary models (Tognelli et al. 2011), with solar-calibrated parameters. Spots were taken into account by adopting a fully-consistent approach, i.e. by incorporating their effects in the evolutionary code, following Somers & Pinsonneault (2015). We assumed an effective spot coverage factor $\beta_{\rm spot}$ ranging from 0 (standard model) to 40%. Here we present preliminary results, obtained by fitting

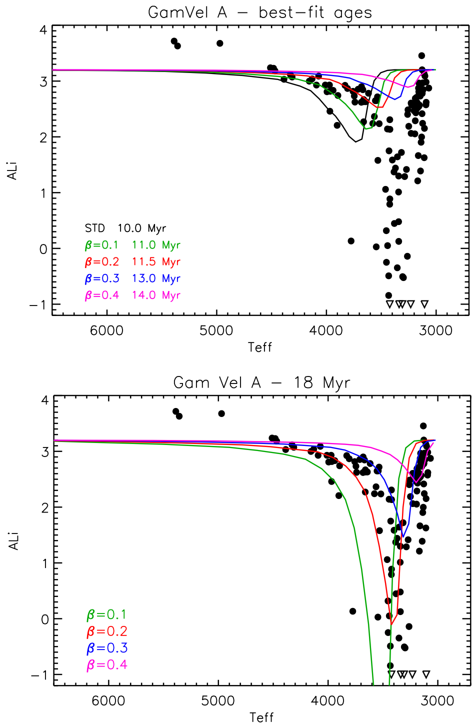

Fig. 2. Comparison of the lithium pattern of Gamma Vel A with the predicted isochrones from the standard and spotted models, at the ages derived from the best-fits (*top*), and assuming an age of 18 Myr for all models (*bottom*).

the cluster CMDs separately for each model using a Bayesian approach.

In the top panel of Fig. 2 we compare the lithium pattern of Gamma Vel A with the model isochrones at the best-fit ages for each model. Although increasing the spot coverage moves the pattern towards lower temperatures as desired, it is clear that the ages derived from the CMD (10–14 Myr) are too low to explain the observed lithium depletion. If, on the other hand, we artificially increase the age of all models to 18 Myr (bottom panel of Fig. 2), consistently with the lower age found by Jeffries et al. (2017), a combination of models with $\beta_{\rm spot} \gtrsim 20\%$ appears to reproduce reasonably well the lithium pattern, but the agreement with the CMD worsens. Similar results are found for Gamma Vel B. We are currently investigating the possible causes of this discrepancy, to see whether we can improve the fit and obtain a better agreement between the CMD and lithium.

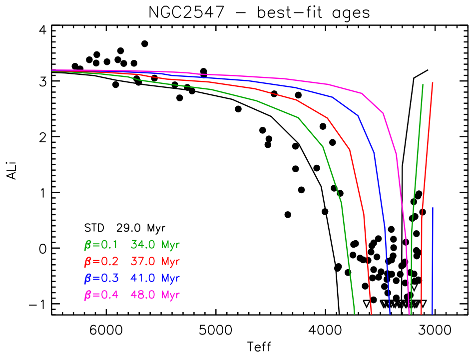

Fig. 3. Comparison of the lithium pattern of NGC 2547 with the predicted isochrones from the standard and spotted models at the ages derived from the best-fits.

Fig. 3 shows the best-fit models for NGC 2547. Contrary to Gamma Vel, at the age of NGC 2547 the standard model reproduces well the observed pattern for the bulk of the stars. The models with 10–20% spot coverage however could explain the observed abundance spread. Similar results hold for the similar-age cluster NGC 2451 B, as well as for the older NGC 2516 cluster.

4. Conclusions

The GES dataset of lithium in young clusters allows us to put strong constraints on pre-main sequence evolutionary models. In particular, we confirm that standard models are not able to reproduce the observed lithium depletion pattern of Gamma Vel, at an age $\lesssim 20$ Myr (Jeffries et al. 2017).

We presented a preliminary comparison of a set of models including spots with the lithium pattern of four clusters of ages 10 – 100 Myr observed by GES. Our results suggest that spotted models with $\gtrsim 20\%$ spot coverage might be promising in reproducing the lithium pattern at 15–20 Myr, but there is a mismatch with the CMD which requires further investigation.

At larger ages, we found instead a good agreement with standard models. At these ages, spots are not necessarily required, although a moderate spot coverage ($\lesssim 20\%$) in some stars could explain the observed abundance spreads.

We are planning to extend our investigation to other young clusters available in GES, that might provide additional constraints to the models, as well as to the additional sample of young open clusters that will be available in the near future from WEAVE.

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