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Lithium, rotation and metallicity in the open cluster M35

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Abstract

Lithium (Li) abundance is an age indicator for G, K and M stellar types, as its abundance decreases over time for these spectral types. However, despite the observational efforts made over the past few decades, the role of rotation, activity and metallicity in the depletion of Li is still unclear. We have investigated how Li depletion is affected by rotation and metallicity in G and K members of the roughly Pleiades-aged open cluster M35. To do so, we have collected a sample of 165 candidate members observed with the WIYN/Hydra spectrograph. In addition, we have taken advantage of three previous spectroscopic studies of Li in M35. As a result, we have collected a final sample of 396 stars which we have classified as members and non-members of the cluster. We have measured iron abundances, Li equivalent widths and Li abundances for the 110 M35 members added to the existing sample by this study. Finally, rotation periods for cluster members have been obtained from the literature or derived from Zwicky Transient Facility light curves. As a result, we have confirmed that fast G and K rotators are Li-rich in comparison with slow rotators of similar effective temperature. Furthermore, while we derived subsolar metallicity for M35 from our spectra, the distribution of Li in this cluster is similar to those observed for the Pleiades and M34, which have solar metallicity and slightly different ages. In addition, we have shown that an empirical relationship proposed to remove the contribution of the Fe I line at 670.75 nm to the blended feature at 670.78 nm overestimates the contribution of this iron line for M35 members. We conclude that a 0.2-0.3 dex difference in metallicity makes little difference in the Li distributions of open clusters with ages between 100 and 250 Myr.

1 Introduction

As lithium (Li) is gradually destroyed in the interiors of solar-like F, G, and K main-sequence (MS) stars, the abundance of this element is used as an age indicator for these stars. Li depletion is driven by convection, but additional factors play an important role in this process. A connection between Li depletion and rotation was first observed in the 90s for the Pleiades [1] and it has been confirmed during the last decades by several authors. Different explanations have been proposed for this link, some of them based on a connection between rotation, Li depletion, and magnetic activity [2, 3]. In addition, stars with lower metallicity have thinner convective envelopes and, consequently, their Li depletion is less efficient. As a result, an anti-correlation between metallicity and Li abundance arises [4]. To completely understand the role these factors play in Li depletion, it is crucial to have a reliable and extensive set of observations of MS FGK stars. As the members of open clusters share the same age and metallicity, they constitute the perfect targets for these observations. To shed more light on this issue, we have investigated how Li depletion is affected by rotation and metallicity in G and K members of M35, an open cluster that is often thought of as a much richer analog of the Pleiades.

2 Preparing the sample

2.1 Collecting spectroscopic data

Our sample is made up of M35 candidate members observed with the Hydra multifiber spectrograph. The blue cable of this instrument provides spectra with resolution R $\approx$ 20 000 covering the wavelength range between 300 and 800 nm.

From 1999 December 12–15, eight science images were taken for 76 sources using the Hydra blue fiber cable. In addition, from 2001 February 22–23, five science images were taken for 89 different candidates with the same cable. We obtained the smoothed and continuum-normalized spectrum corresponding to each source in each of the images using standard IRAF tools.

To increase the size of our sample, we took advantage of previous works that also used Hydra to collect spectra for M35 candidate members. We included in our sample the G and K dwarfs studied by [5] and [6]. The former measured Li equivalent widths (EWs) for 85 M35 candidates, whereas the latter provided Li EWs for 76 G and K dwarfs. Finally, we added to our sample 100 stars observed by [7]. These stars were rejected by the authors of that study because they considered them non-members of the cluster, found no rotation periods for them, or because these objects exhibited a poor fit when analysed with the Virtual Observatory Spectral Energy Distribution (SED) Analyser [8].

As a corollary, we ended up with a final sample of 396 unique G and K candidate members of M35 for which we could obtain or have Li measurements. The different Hydra campaigns we have used to build our sample are summarized in Table 1. Note that some M35 candidate members were observed in more than one campaign.

Table 1: Summary of our complete sample in terms of the origin of the spectroscopic data.

Campaign	Number of Sources	Authors
1998 January	76	[6]
1999 December	76	[9]
2001 February	89	[9]
2001 March	85	[5]
2017 November	100	[7]

2.2 Revisiting the membership and multiplicity of stars in our sample

We used *Gaia* DR3 photometry and the magnitudes provided by [10] to build color-magnitude diagrams (CMDs) for the sources in our sample (see Fig. 1). These CMDs allowed us to identify 16 stars as photometric non-members.

We then used Clusterix 2.0 [11] to derive membership probabilities for the stars in our sample from their *Gaia* EDR3 proper motions. The M35 members identified in this way were added to the candidates with membership probabilities $\geq 50\%$ in [10], concluding that 251 of the 396 candidates studied were members of the cluster.

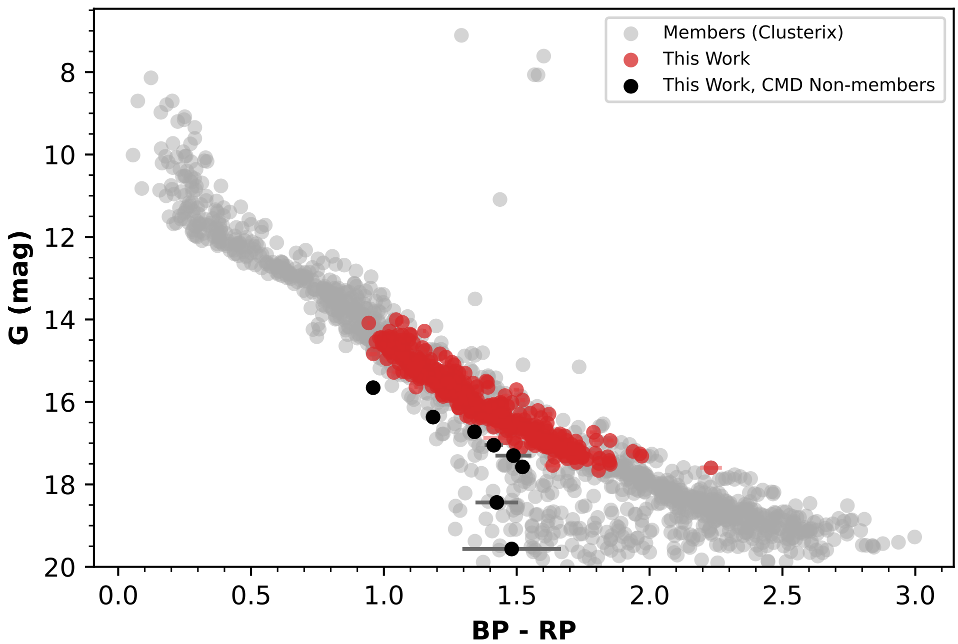

Figure 1: *Gaia* DR3 CMD for M35. Adapted from [9].

Finally, we employed iSpec [12] to obtain radial velocities (RVs) from the spectra collected in December 1999 and February 2001 with the aim of identifying spectroscopic binaries (SBs) for this part of the sample. On the other hand, we took advantage of the M35 SBs identified by [6] and [13] for the rest of our sample. In addition, we flagged those sources with large Renormalised Unit Weight Errors in Gaia DR3 as wide binaries. To sum up, we found 88 multiple systems in our sample.

2.3 Assembling our sample of rotation periods

In order to get rotation periods for the 251 members of the cluster found in our sample we extracted differential photometry from the archival Zwicky Transient Facility imaging and computed Lomb-Scargle periodograms from the resulting light curves. Besides this, we took advantage of previous studies that employed K2 photometry [14, 15] or ground-based facilities [16, 17] to derive rotation periods for M35 members. In the end, we obtained periods for 197 M35 members observed with Hydra.

3 Analysis

To obtain effective temperatures and luminosities for the M35 members in our sample we uploaded to VOSA [8] the photometry collected from [6] and [10]. In addition, we cross-matched these sources with several photometric catalogues, obtaining more points for their SEDs. The resulting SEDs where dereddened assuming a visual extinction in the direction of the cluster of $A_V = 0.62$ [7]. Finally, we used the Kurucz model atmospheres, assuming log $g = 4.5$ and a solar metallicity, to determine the luminosity and effective temperature that best fit each SED using a χ-squared minimisation method.

We used iSpec to combine RV-corrected versions of the spectra collected in December 1999 and February 2001. The same software was used to develop the pipeline to derive Li EWs and Li abundances from the combined spectra. First, we used the SPECTRUM radiative transfer code, the MARCS model atmospheres, and the Gaia–ESO survey line list to generate, for each star, a synthetic $R = 20\,000$ spectrum with solar metallicity, log $g = 4.5$, and the effective temperature returned by VOSA. This process was repeated several times until we found the v sin i that best fits the science spectrum. Second, we determined the iron abundance for each star using 40 Fe lines between 645 nm and 680 nm together with the aforementioned stellar parameters. Once the v sin i and the Fe abundance had been determined, we derived the EW of the Li doublet at 670.78 nm as well as the local thermodynamic equilibrium (LTE) Li abundance.

However, as the resolution of the spectra is not high enough to separate the Li doublet at 670.78 nm and the Fe I line at 670.75 nm, both features are blended. To estimate the contribution of this iron line, we tried two different approaches. On the one hand, we generated synthetic spectra employing a modified version of the Gaia–ESO line list where all the Li lines had been removed. On the other hand, we used the empirical relation derived by [1]. We observed that the iron EWs obtained by the former approach were 5-15 m$\mathring{A}$ lower than those obtained by the latter. We concluded that the empirical relation proposed by [1] overestimates the contribution of the Fe I line for subsolar metallicity clusters, such as M35.

4 Results

To study the effect of metallitiy on the Li depletion, we derive the metallicity of M35 as the average of the iron abundances obtained for the single stars with the highest probability of belonging to M35 and effective temperatures > 4500 K, obtaining a metallicity of [Fe/H] = -0.26 ± 0.09. This result is fully consistent with the values published in [6] and [18].

On the other hand, to study the effect of rotation on the Li depletion we built the diagram shown on Fig. 2, which is a color-period diagram (CPD) in which we indicate the relative Li abundances of the stars in M35. The most striking result is that M35 fast rotators of G and K spectral types are Li-rich compared with slow rotators of similar effective temperature. This result is consistent with the pattern described in [5], [6], and [7] for the M35 open cluster as well as with the trend found for other stellar associations. The aforementioned pattern is more evident in the bottom panel, where multiple systems are not included.

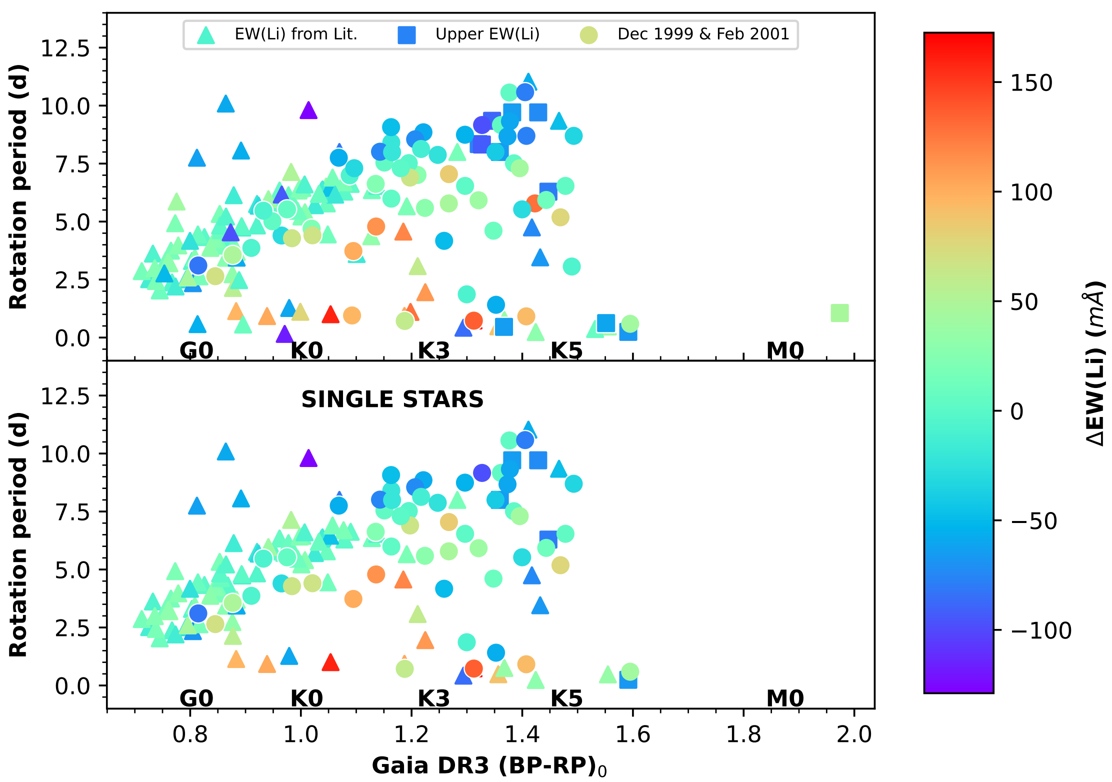

Figure 2: Color-period diagram for the M35 members in our sample. Adapted from [9].

We took advantage of previous studies to build similar CPDs for the Pleiades [19, 20] and M34 [21]. The former is an open cluster with solar metallicity and $127.4^{+6.3}_{-10}$ Myr [22]. On the other hand, M34 has also solar metallicity but its age is between 178 and 250 Myr [23, 24]. We have selected these clusters because the age of M35 is between theirs. Despite a difference of 0.2-0.3 dex in metallicity, the Li distributions of both clusters are very similar to the one shown on Fig. 2 for M35. To confirm this, we performed Kolmogorov-Smirnov tests between the aforementioned distributions, obtaining p-values coherent with a similar origin for the three samples compared. As a result, we concluded that a 0.2–0.3 dex difference in metallicity does not have an observable impact on the Li distributions of open clusters with ages between 100 and 250 Myr.

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