The *Gaia*-ESO Survey: Calibrating the lithium-age relation with open clusters and associations

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Abstract

The large number of stars observed within the Gaia-ESO survey (**GES**)* for many **open clusters and associations** can be used to **calibrate the lithium-age relation** and its dependence with **other parameters**. This relation will ultimately allow us to **infer the ages of GES field stars** and identify their potential membership to young associations and stellar kinematic groups. In the present work we performed a thorough analysis of **membership and Li abundance of 20 clusters** observed in **GES (iDR4)**, ranging in age from **young clusters and associations**, to **intermediate-age and old open clusters**, to conduct a comparative study. All this allowed us to characterize the properties of the members of these clusters, as well as identify a series of **field contaminant stars, both lithium-rich giants and non-giant outliers**.

* https://www.gaia-eso.eu/

Context

- In solar-type and lower mass stars, lithium is slowly being depleted and its surface abundance decreases over time. For this reason, **lithium is a very sensitive tracer of stellar evolution**, and is particularly relevant in the determination of the age of stellar clusters.

- **Li depletion** is strongly **age-dependent** but currently available data have shown a complex pattern of Li depletion on the pre- and main-sequence stars that is not yet understood. The lithium abundance observed in late-type stars depends not only of the age and the temperature but also on metallicity, mixing mechanisms, convection structure, rotation and magnetic activity.

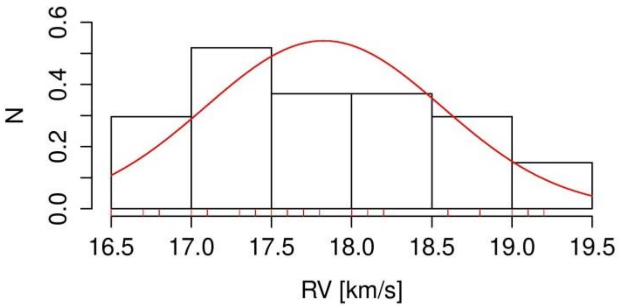
- In the present work we use lithium, among other criteria, in order to **constrain the cluster membership of a series of open clusters and associations** using data from GES. The membership analysis and calibration of the ages of open clusters and associations is of great importance in order to study the **lithium-age relation**, which will allow us to use lithium as an effective age indicator to analyze field stars from GES whose age is still unknown.

- The **Gaia-ESO Survey** (**GES** - Gilmore et al. 2012; Randich et al. 2013) is a large, public spectroscopic survey that provides an homogeneous overview of the distribution of kinematics, dynamical structure and chemical compositions in the Galaxy. GES uses the multi-object spectrograph **FLAMES** on the Very Large Telescope (ESO, Chile) to obtain both high resolution spectra with **UVES** (Ultraviolet and Visual Echelle Spectrograph) and medium resolution spectra with **GIRAFFE**. Regarding the GES working groups (WGs), **WG11** and **WG12** are focused on the spectroscopic analysis of FGK stars and stars in the fields of young clusters, respectively, using both UVES and GIRAFFE data.

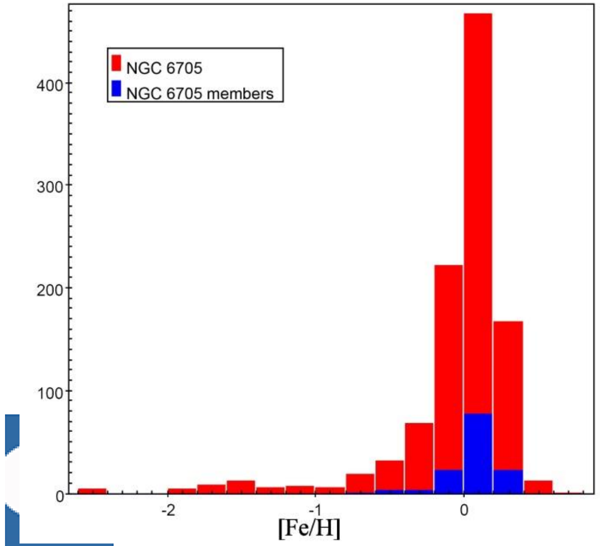
- For this work we used the data provided by the fourth internal data release of GES (**iDR4**), including UVES and GIRAFFE spectra of **20 open clusters of ages ranging from 1 Myr to 5 Gyr.** In our future work we will be using the last GES **iDR6** data release**.**

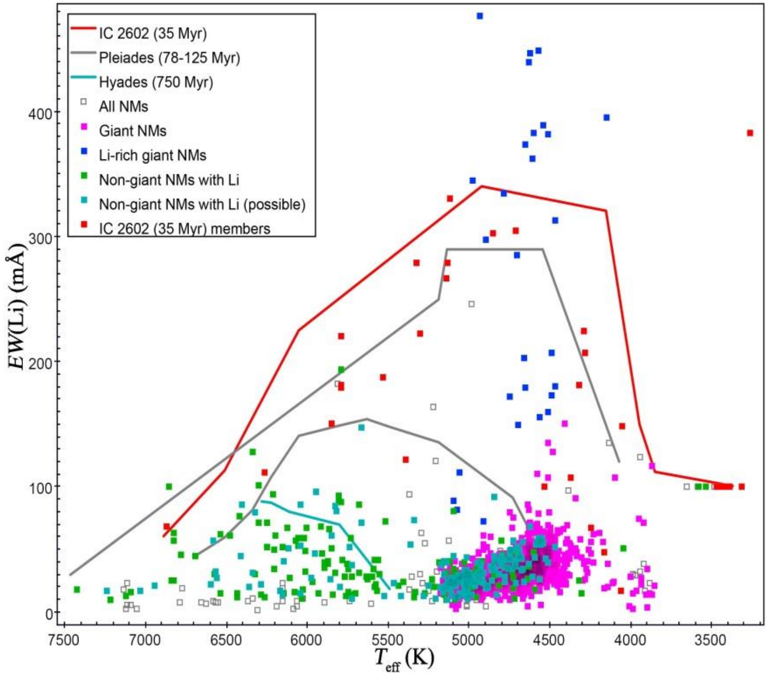
Methodology

We obtained lists of candidate members for each cluster based on their *RV*s, the position in the *EW*(Li) vs T_{eff} (our main criterium), gravity indicators - Kiel (log*g* vs T_{eff}) and γ index diagrams, and their [Fe/H] metallicity. As and example, we show here the case of **IC 2602** (RV, *EW*(Li) vs T_{eff} and γ index) and **NGC 6705** (Kiel diagram and [Fe/H] histogram):



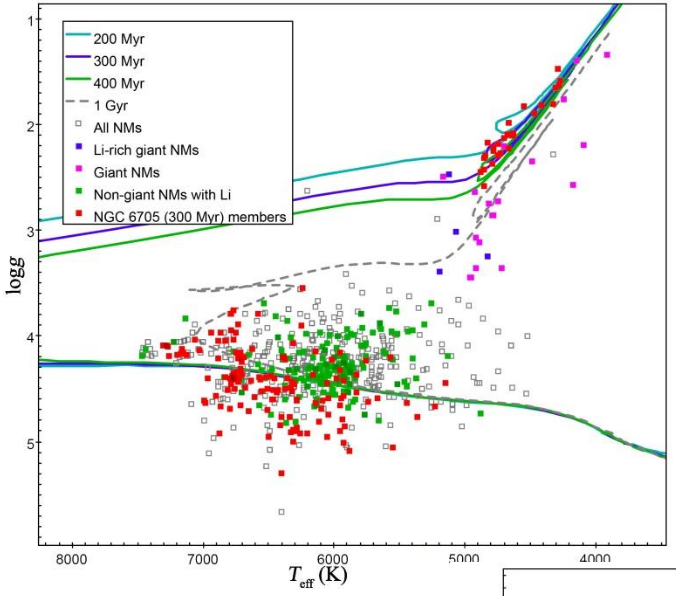
1) Kinematic selection: We studied the RV distribution of each cluster by applying a **2-sigma clipping procedure** and adopting a 2σ limit about the cluster mean yielded by the **Gaussian fit** to identify the most likely **RV members**.





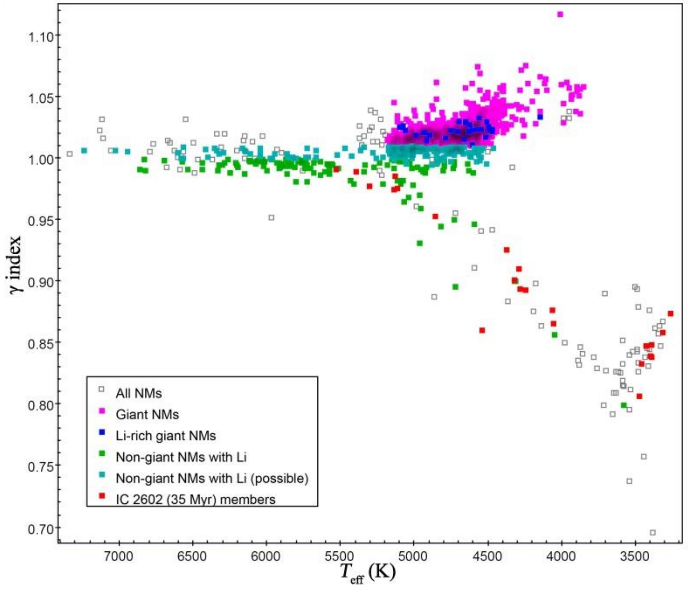
2) *EW*(Li) vs T_{eff}: By plotting the **lithium envelopes of IC 2602 (35 Myr), the Pleiades (78-125 Myr), and the Hyades (750 Myr)** in a *EW*(Li) vs T_{eff} figure, we can estimate age ranges for the cluster candidate stars and identify probable members among the kinematic candidates.

4) [Fe/H] histograms also help rule out stars with metallicities too far away from the mean for each cluster.



3) The **Kiel diagram** enables us to **discard giant outliers** (log*g* < 3.5) – some of them Li-rich giants (A(Li)>1.5) – and other field contaminants. We used the **PARSEC isochrones** ([Bressan et al. 2012](#)), with Z=0.019 and ages ranging from 1 Myr to 7 Gyr. For young clusters, we also used the gravity indicator gamma in **Gamma index vs T_{eff}** diagrams.

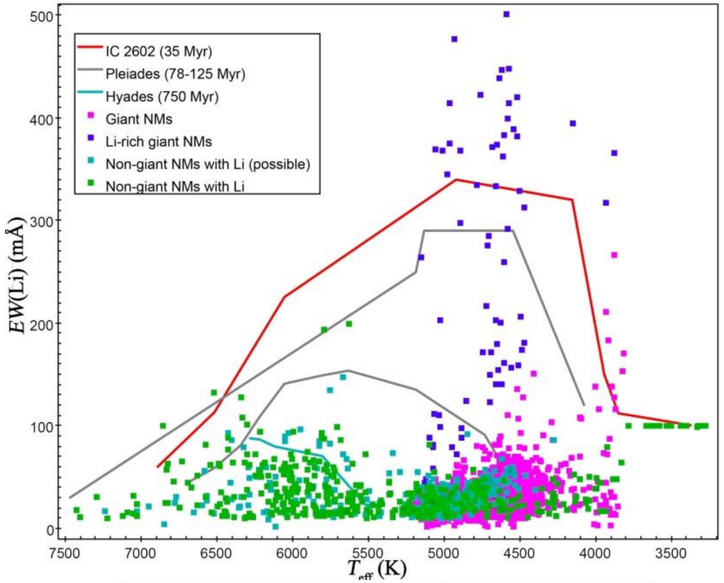
5) In addition, we also used a series of studies using data from ***Gaia* DR1 and DR2** to further assess the membership of our candidate selections. These studies include [Cantat-Gaudin et al 2018](#), [Randich et al 2018](#) and [Cánovas et al 2019](#).

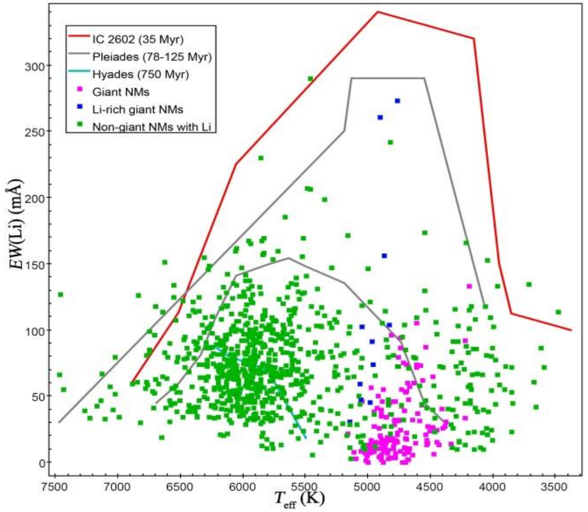


Results

The table below shows **the 20 open clusters analysed** (covering a range of **age from a few Myr to 5 Gyr**), indicating the number of stars with Li detected in UVES and GIRAFFE, the number of stars selected as final candidates (with additional possible members indicated in parentheses), and the number of giant (G) and non-giant (NG) outliers of interest (shown as an example on the right in the EW(*Li*) vs T_{eff} diagrams for the young (top) and intermediate and old clusters (bottom):

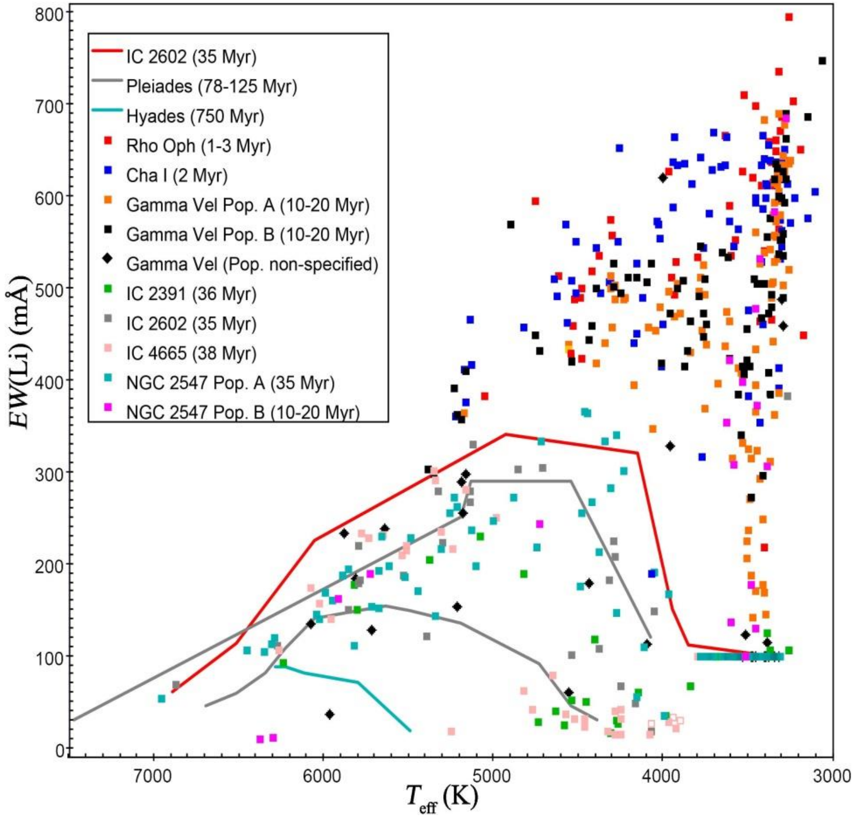
Name	*Age (Myr)*	*[Fe/H] (dex)*	*RV (km/s)*	*Nº* UVES w/ Li*	*Nº* GIRAFFE w/Li*	*Nº * Final members*	*NG outliers*	*G outliers*	*Li-rich giant outliers (A(Li)>1.5)*
ρ Ophiuchi	1-3	-0.07	-7.0	23	231	**45**	**48(75)**	**90**	**2**
Chamaeleon I	2	-0.07	14.6	39	473	**85**	**44(76)**	**247**	**9**
γ Velorum	10-20	-0.06	15.5	60	855	**210**	**13(14)**	**506**	**14**
NGC 2547	35-45	-0.03	14.8	25	278	**107**	**-**	**122**	**3**
IC 2391	36	-0.03	15.3	23	360	**27**	**18(67)**	**253**	**10**
IC 2602	35	-0.02	17.4	115	1465	**32**	**138(244)**	**1212**	**28**
IC 4665	38	0.00	-14.4	32	534	**37(40)**	**168(244)**	**133**	**2**
NGC 2516	251	-0.06	23.8	33	429	**298**	59	70	0
NGC 6705	300	+0.16	36.0	31	309	**163**	166	19	6
NGC 4815	570	+0.11	-29.8	11	46	**29**	23	5	0
NGC 6633	773	-0.01	-28.6	42	354	**101(118)**	**186**	**590**	**13**
Trumpler 23	800	+0.21	-61.4	15	17	**17**	**11**	**4**	**1**
Berkeley 81	860	+0.22	50.0	14	77	**28**	**60**	**0**	**0**
NGC 6005	973	+0.19	-25.6	19	89	**38**	**62**	**17**	**1**
NGC 6802	1000	+0.10	11.8	13	29	**22**	**14**	**2**	**3**
Pismis 18	1200	+0.22	-28.5	10	30	**15**	**23**	**1**	**0**
Trumpler 20	1500	+0.10	-39.8	41	214	**124**	**122**	**15**	-
Berkeley 44	1600	+0.27	-7.6	7	43	**22**	**28**	**4**	**0**
M67	4000-4500	-0.01	34.1	20	0	**18(19)**	**1**	**0**	**0**
NGC 2243	4000	-0.38	59.6	26	108	**36**	**90**	**7**	**7**



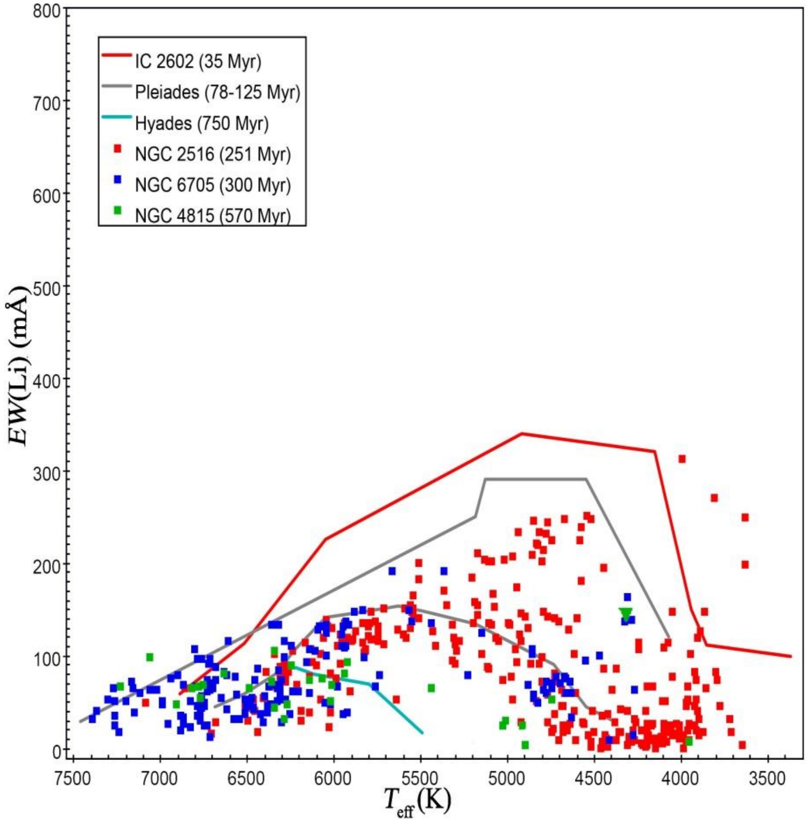


Results

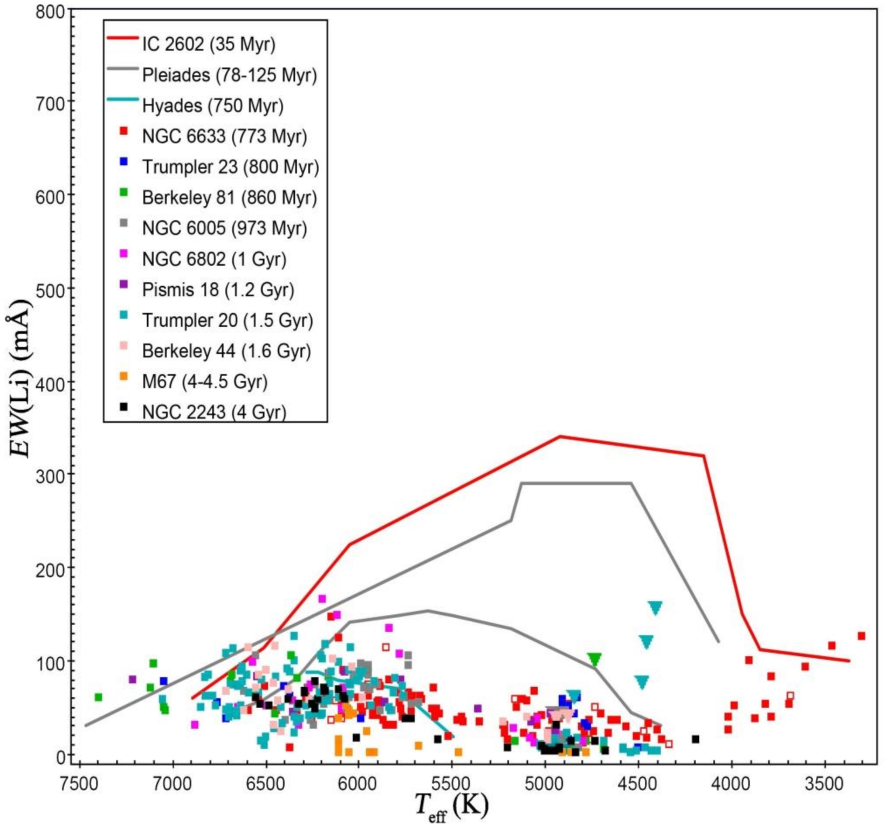
Young clusters (1-50 Myr)



Intermediate –age clusters (50-700 Myr)



Old clusters (>700 Myr)



***EW*(Li) vs T_{eff} diagrams for the candidate members** of the **young clusters** (1-50 Myr, left panel), as well as the **intermediate-age** (50-700 Myr, middle panel) and **old clusters** (>700 Myr, right panel). We also show the **lithium envelopes** of **IC 2602** (35 Myr, red), the **Pleiades** (78-125 Myr, grey), and the **Hyades** (750 Myr, turquoise). **Open squares** indicate possible members only, while **inverted triangles** refer to Li-rich members**.**

Impact and prospects for the future

In this work we used the data provided by the fourth internal data release (iDR4) of the Gaia-ESO Survey (GES) in order to conduct an analysis of the membership and Li abundance of the selected 20 young, intermediate and old clusters. This first publication will be available shortly: **The *Gaia-ESO* Survey: Calibrating the lithium-age relation with open clusters and associations. I. Cluster age range and initial membership selections (Gutiérrez Albarrán et al. 2020. A&A, accepted).**

We are working on a detailed analysis of the **dependence of the lithium-age relation on other stellar parameters** derived from the GES spectroscopic observations, such as the level of chromospheric activity (Hα), accretion indicators, and rotation (*v*sin*i*), and other parameters available from the literature. The **age** of each cluster will be revised using all this information, as well as the lithium depletion boundary whenever possible.

- We also aim to update all the selections of cluster members and contaminants presented in this study using both the **GES iDR6 data release**, and data from **Gaia DR2**. This will also allow us to add **new clusters** to our calibration and contribute to better constrain the lithium-age relation.

- We plan on using **the lithium-age relation** derived during this project to derive the **ages of GES field stars**, as well as search or confirm the membership of these field stars to **young associations and stellar kinematic groups of different ages**. We are also studying in more detail some unknown non-member contaminants in the field of these clusters, **Li-rich stars, and giant and non-giant outliers with Li** -, which could be possible new young field stars or Li-rich giants.

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