The lithium-age relation:
Calibration with open clusters and associations

M.L. Gutiérrez Albarrán[1], D. Montes[1], H.M. Tabernero[1,2], J.I. González Hernández[3,4], A. Frasca[5], A.C. Lanzafame[5], R. Smiljanic[6], A.J. Korn[7], S. Randich[8], G. Gilmore[9], et al. & GES Survey Builders

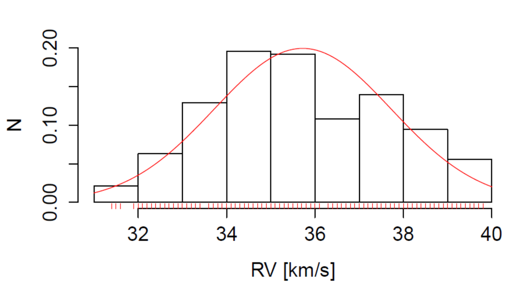
[1]Departamento de Física de la Tierra y Astrofísica and IPARCOS-UCM, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, E-28040, Madrid, Spain; [2] CAB; [3] IAC; [4] Universidad de la Laguna, Tenerife; [5] INAF Catania; [6] Nicolaus Copernicus Astronomical Center; [7] Department of Physics and Astronomy, Uppsala University; [8] INAF Arcetri; [9] Institute of Astronomy, University of Cambridge

Abstract

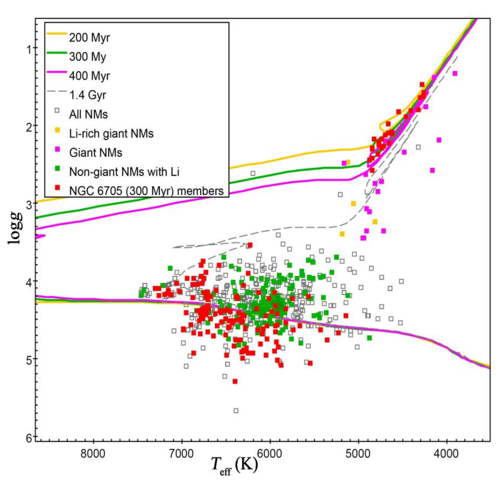
In this work we used a series of open clusters and associations observed by the **Gaia-ESO Survey (GES)** to study the use **of lithium abundances** (Li I spectral line at 6708 Å) **as an age indicator for pre- and main-sequence FGKM late-type stars**. Previous studies of open clusters have shown that lithium depletion is not only strongly age dependent, but also shows a complex pattern with several other parameters, such as rotation, chromospheric activity and metallicity. Using the available data from both **GES iDR6 and Gaia EDR3**, we performed a thorough **membership analysis** and **obtained lists of candidate members for 42 open clusters, ranging in age from 1-3 Myr to 4.5 Gyr.** We then conducted a comparative study that allowed us to quantify the observable lithium dispersion in each cluster and **study the influence of rotation, activity and metallicity in the lithium dispersion of the selected candidates**. All this allowed us to **calibrate a Li-age relation and create empirical lithium envelopes** for 27 of of the 42 sample clusters, also constraining the **LDB** for those clusters in the 15-600 Myr age range.

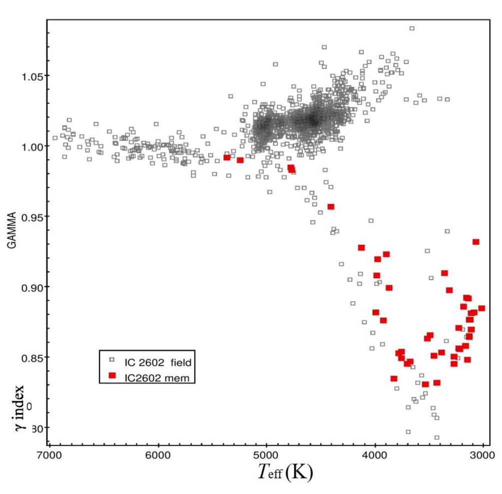
Selection criteria and cluster membership

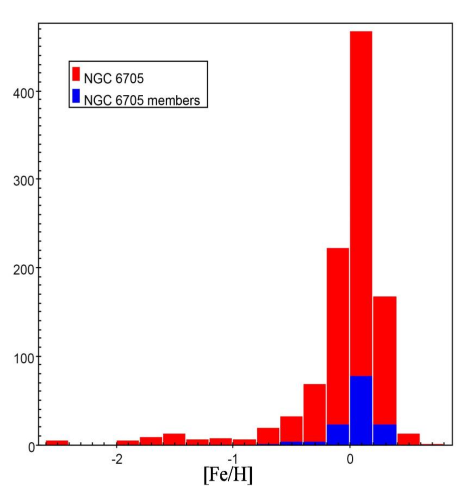
Candidate members for each cluster are selected from the **Gaia-ESO Survey (GES)** (Gilmore et al. 2012) **iDR6** data based on the following criteria: *RVs*, *Gaia* astrometry (proper motions and parallaxes), gravity indicators - Kiel (logg vs T_{eff}) and γ index diagrams -, [Fe/H] metallicity, and the position in the *EW*(Li) vs T_{eff} diagram. As an example we show here the case of **IC 2602** (*PMs*, *CMD*, *EW*(Li) vs T_{eff} and γ index) and **NGC 6705** (*RV*, Kiel diagram and [Fe/H] histogram):



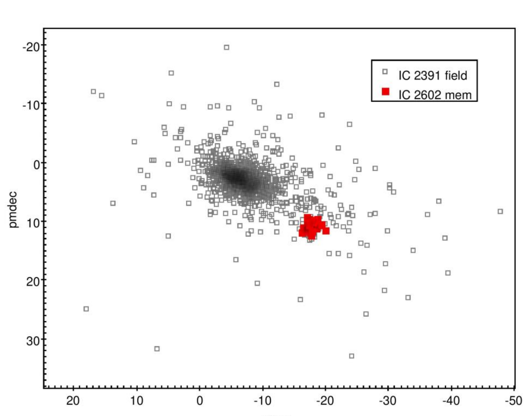
Kinematic selection: We studied the RV distribution of each cluster by applying a **2-sigma clipping procedure** and adopting a 2σ limit about the cluster mean yielded by the **Gaussian fit** to identify the most likely **RV members**.





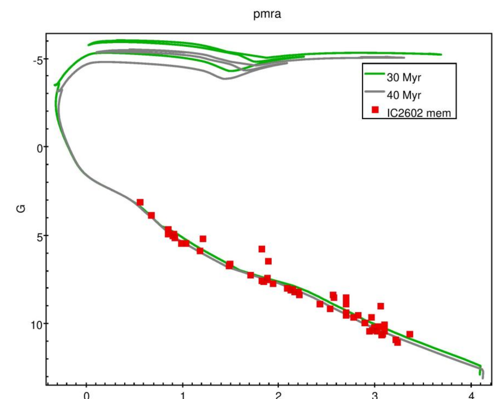


[Fe/H] histograms also help rule out stars with metallicities too far away from the mean for each cluster.



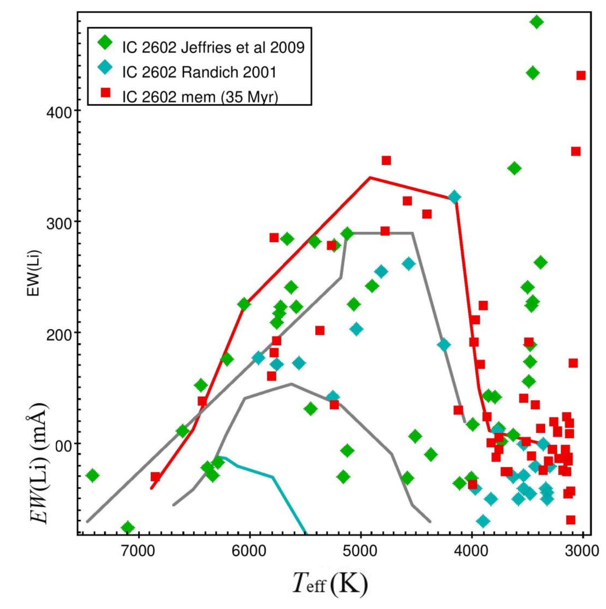
The **Kiel diagram** enables us to **discard giant outliers** (logg < 3.5) – some of them Li-rich giants (A(Li) > 1.5) – and other field contaminants. We used the ***PARSEC* isochrones** (Bressan et al. 2012), with *Z* = 0.019 and ages ranging from 1 Myr to 7 Gyr. For young clusters, we used the **gravity indicator gamma** (see **γ index vs T_{eff}** diagram above) to discard giant contaminants before applying any kinematic and astrometric criteria.

***Gaia* astrometry**: Alongside the RVs measured by GES. We use the **proper motions and parallaxes provided by Gaia EDR3** (Gaia Collaboration et al. 2021A&A...649A...1G) to obtain lists of probable astrometric members.



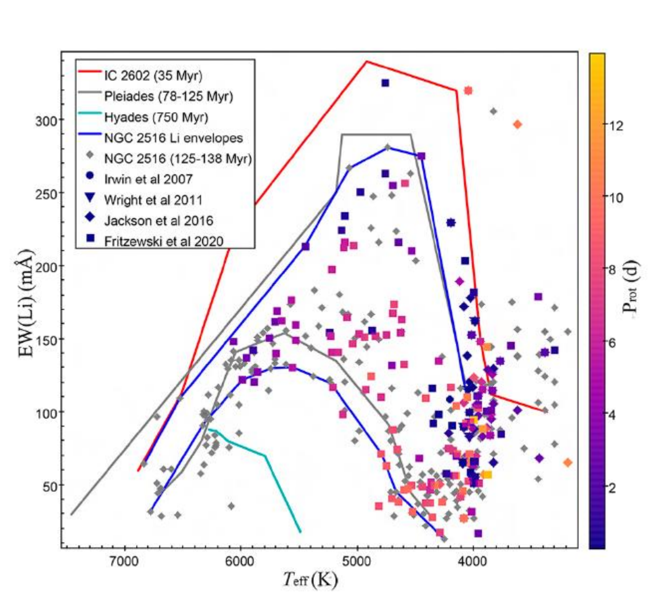
CMDs: We also make use of **Gaia EDR3 photometry** to analyse the membership of our candidates and discard contaminants in ***G* vs G_{BP}-G_{RP} colour-magnitude diagrams.**

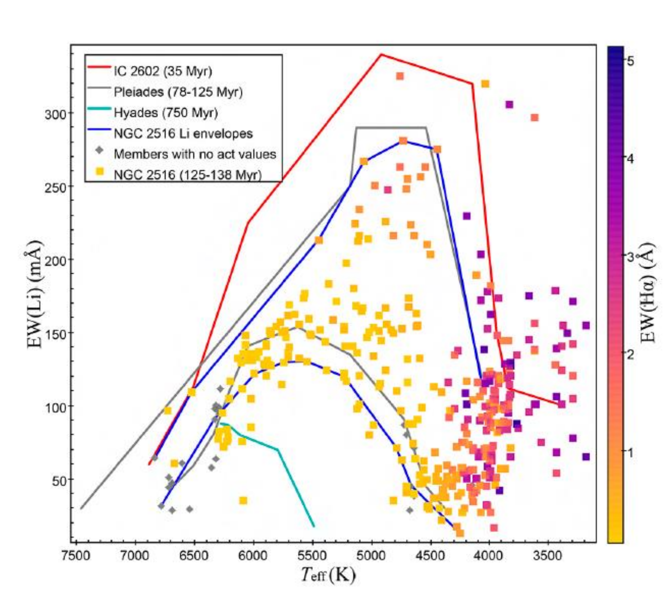
***EW*(Li) vs T_{eff}**: Plotting the **lithium envelopes of IC 2602 (35 Myr), the Pleiades (78-125 Myr), and the Hyades (750 Myr)** in a *EW*(Li) vs T_{eff} figure, we can estimate age ranges and verify probable members (see Montes et al. 2001).



For more details see: Gutiérrez Albarrán, et al. 2020A&A...643A..71G

Dependence with rotation, activity and metallicity. Li-age relation





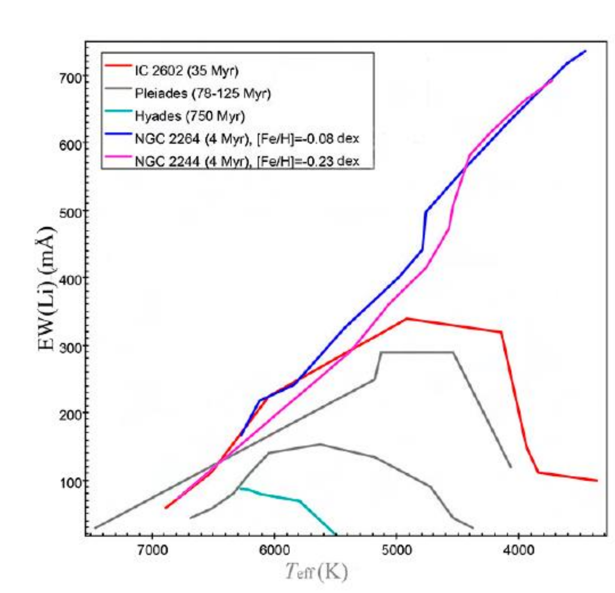
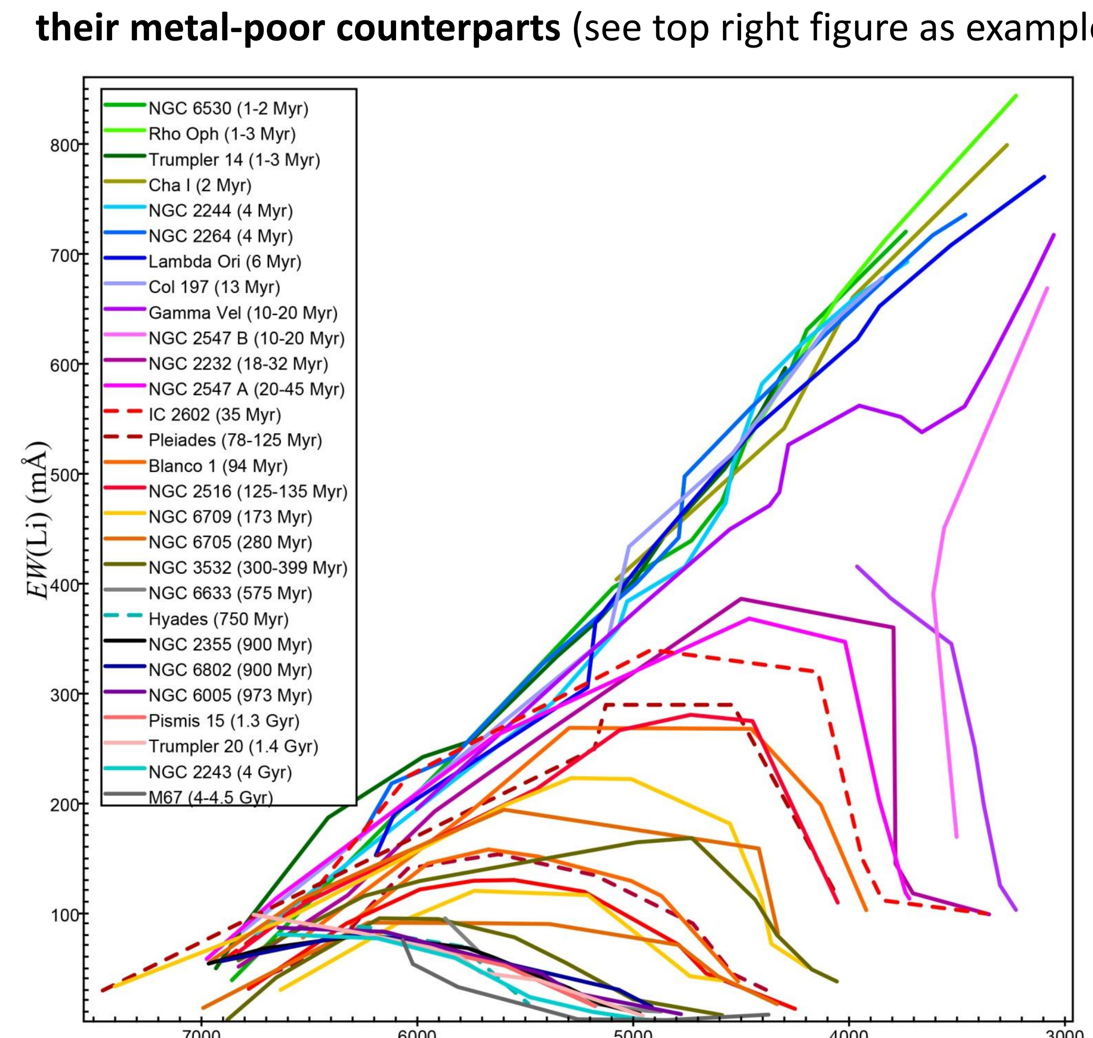
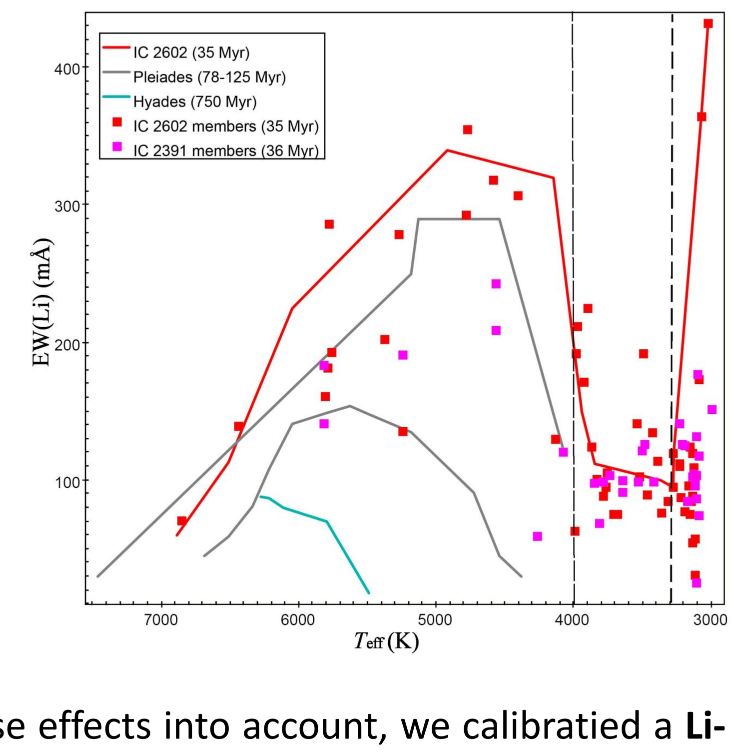


Figure 3.26: $EW(\mathrm{Li})$-versus-T_{eff} diagram comparing the upper Li envelopes for NGC 2244 (4 Myr, [Fe/H]=−0.23 dex) and NGC 2264 (4 Myr, [Fe/H]=−0.08 dex).

We used the **rotational velocities (*v*sini), chromospheric activity indicators (*EW*(Hα)) and [Fe/H] metallicities** provided by **GES iDR6**, as well as additional **rotational periods (P_{rot})** from the literature, including ***Kepler, K2* and *TESS*** measurements. We confirmed the findings of former publications and observed that **members with higher values of *EW*(Li) tend to be faster rotators and have higher levels of activity** (for ex., *EW*(Li)-versus-T_{eff} diagrams above, colour-coded by P_{rot} and Hα for NGC 2516, 125-138 Myr). We additionally observed slight **effects of metallicity in the Li depletion of coeval clusters**: **Metal-rich clusters** seem to show **higher Li abundances than their metal-poor counterparts** (see top right figure as example).



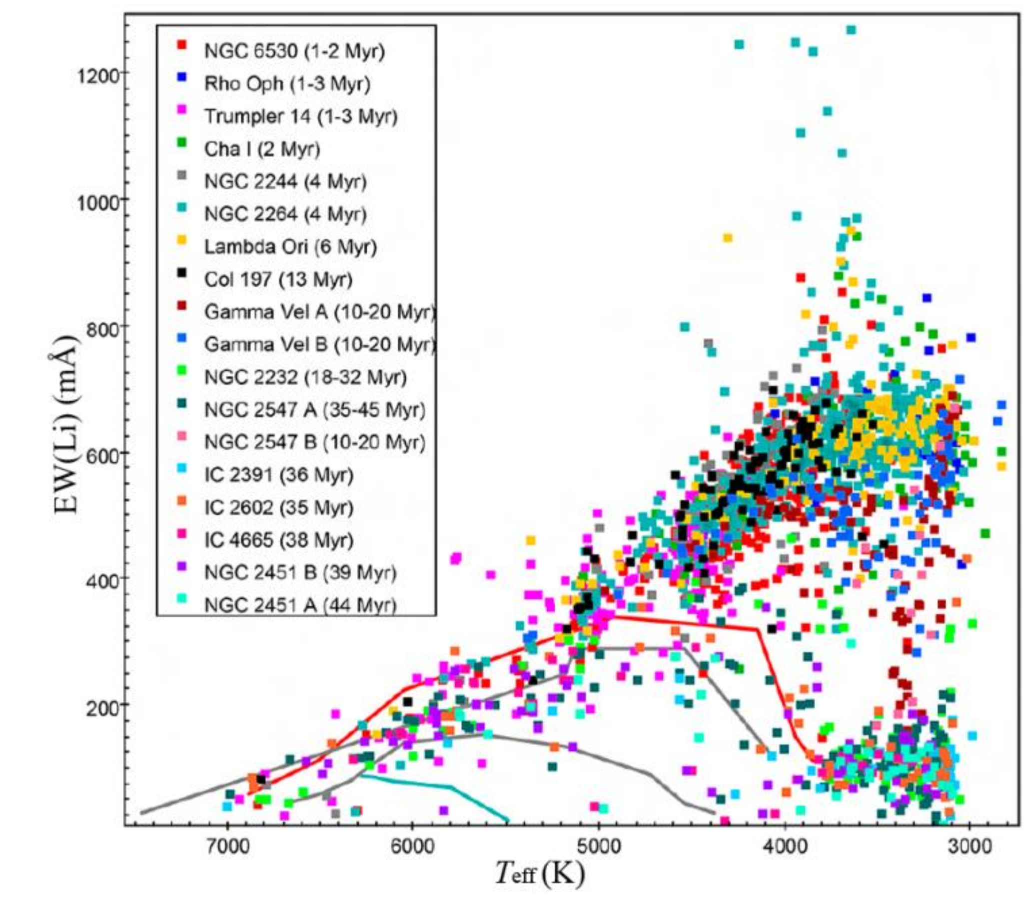


Taking all these effects into account, we calibratied a **Li-age relation** and created **empirical lithium envelopes** for key age ranges in our cluster sample (see figure, left, showing all 27 final envelopes). This Li-age calibration will allow us to **estimate age ranges for GES field stars**. As part of this calibration we also studied **the lithium depletion boundary (LDB)** for clusters in the 15-500 Myr range with the aid of models such as Baraffe et al. 2015 (see vertical dashed lines in the IC 2602 diagram, left).

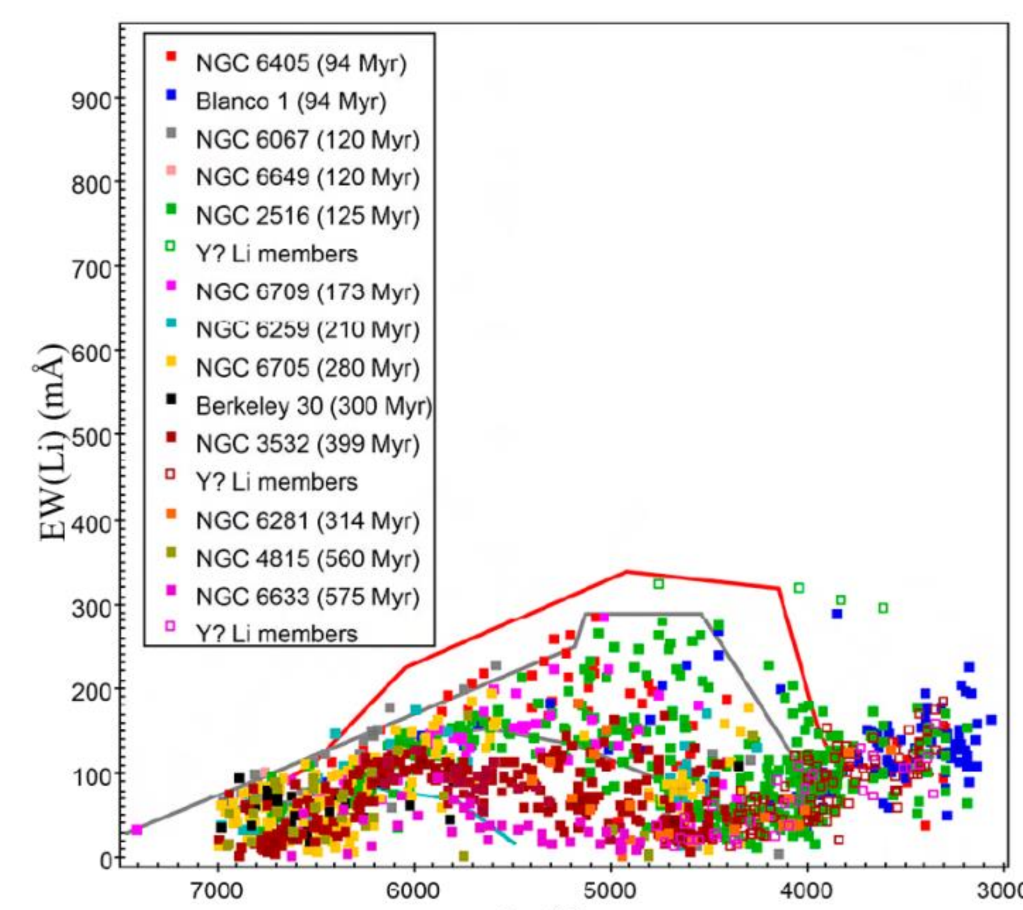
Cluster candidate selections

***EW*(Li) vs T_{eff}**: for the 42 open clusters analysed with data from GES iDR6 (covering a range of **age from 1-3 Myr to 4.5 Gyr**).

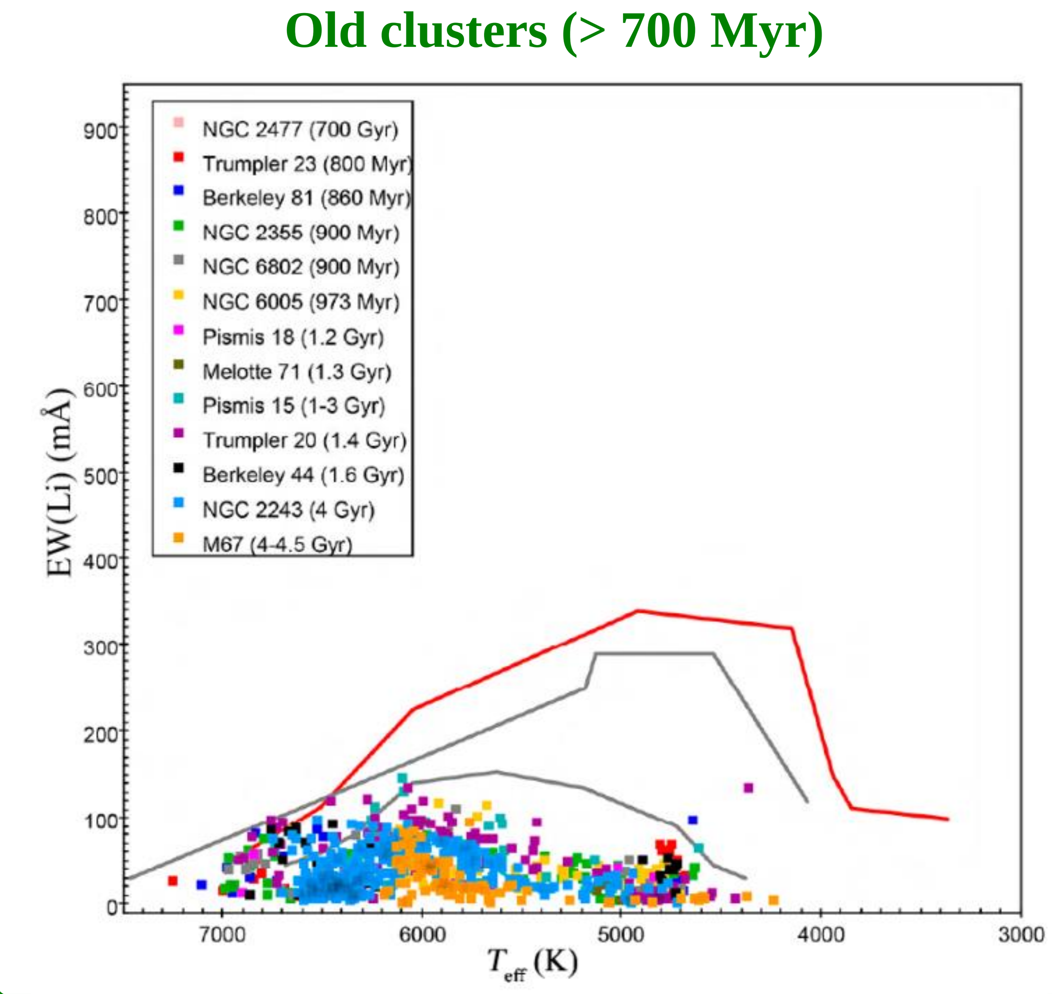
Young clusters (1 – 50 Myr)



Intermediate-age clusters (50 – 700 Myr)



Old clusters (> 700 Myr)



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