Lithium-7 depletion in young open clusters: theoretical models vs observations

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ABSTRACT

The analysis of surface lithium abundance in open clusters is an indirect method to investigate the time evolution of the extension of the stellar convective envelope; in fact during the pre-main sequence and main sequence evolution of low and intermediate mass stars the temperature at the base of the convective zone is high enough to burn lithium. In this work we re-analysed the well known problem of the disagreement between theoretical predictions and data for the surface ^{7}Li in clusters of different chemical composition and ages. In our procedure we rely on homogeneous data of observed ^{7}Li abundances for cluster of different ages and chemical composition making also use of accurate observational colour-magnitude diagrams; the cluster age is directly derived by means of our theoretical isochrones. We show that it is possible to reproduce the ^{7}Li depletion profile for young clusters (age below 100-200 Myr) adopting a value of the pre-main sequence mixing length parameter that is almost independent on both the mass and the chemical composition. Moreover we confirm that the depletion on a time scale larger than 200 Myr is incompatible with the hypothesis of standard mixing and diffusion, within the theoretical uncertainties.

Introduction

The surface ^{7}Li depletion during the pre-main sequence phase (pre-MS) essentially depends on the temperature at the bottom of the convective envelope which is very sensitive to the convection efficiency, that is to the adopted value of the mixing length parameter (hereafter α). Since α is a free parameter to be calibrated with the observations, there is no reason to adopt the same value of α for stars in different evolutionary phase or with different chemical composition.

In the clusters presented here there are no pre-MS stars and thus α_{pms} can not be calibrated directly by the comparison with the color-magnitude diagram (CMD), while α_{ms} is calibrated to reproduce the colour of low and intermediate mass stars. Following this method α_{pms} is a free parameter of our models that we can tune to fit the observed ^{7}Li abundance in a cluster with the assumption that stars of the same cluster have the same α_{pms}.

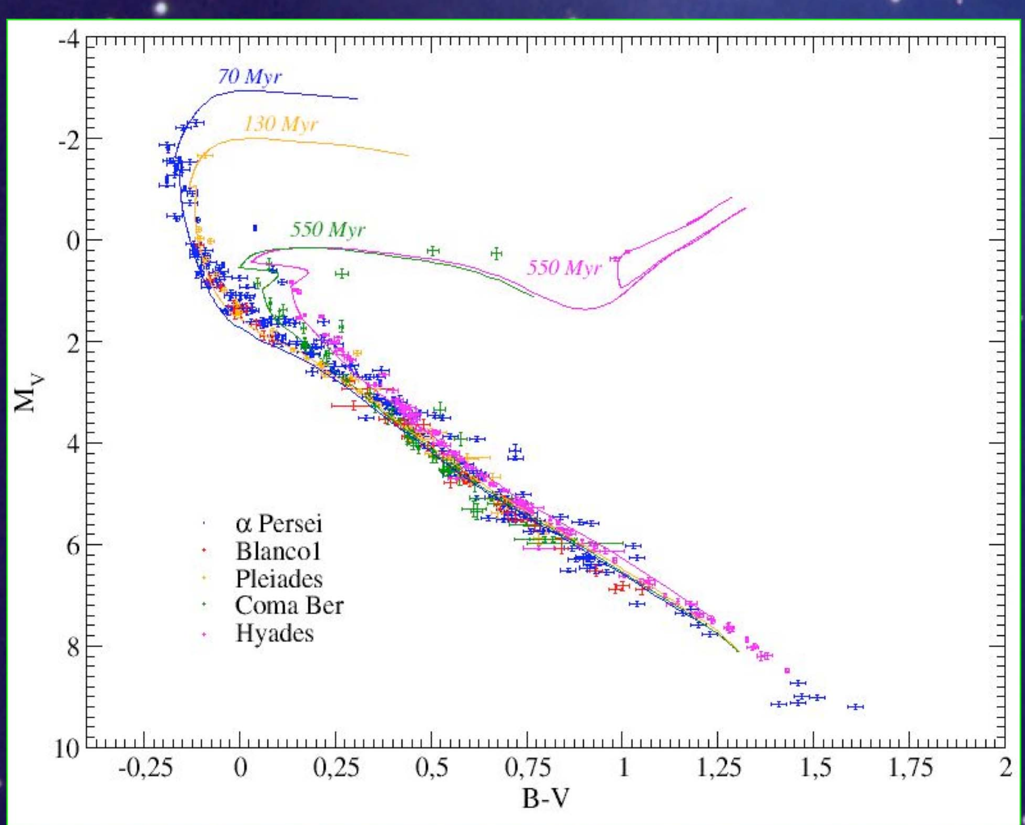
Our method consists in computing evolutionary tracks in the mass range covered by ^{7}Li observational data for different values of α_{pms} up to the onset of nuclear hydrogen burning when the mixing length is restored to the value required to obtain a good agreement with the observed CMD.

The Models

We computed stellar tracks by means of an updated version of the FRANEC stellar evolutionary code. A detailed description of the code can be found in Tognelli et al. (2010). The main physical inputs of the code are: high temperature OPAL opacity tables (2005), low temperature opacities from Ferguson et al. (2005), both computed assuming the solar mixture given by Asplund et al. (2005), OPAL EOS (2006) and boundary conditions obtained from detailed atmosphere models (Castelli & Kurucz 2003; Brott & Hauschildt 2005). The code follows the chemical evolution of the light elements (Li, Be, B), with light elements burning rates from NACRE (Angulo et al. 1999). Diffusion is included in our calculations.

Color-Magnitude Diagrams: age determination

Ages and α_{ms} are obtained by comparing our theoretical isochrones, for the estimated cluster chemical composition, with the observed CMDs. This is needed to obtain in a consistent way both the age of the cluster and the effective temperature of those stars for which the surface ^{7}Li abundance has been mesured.



Color-Magnitude Diagram for the selected clusters presented, with overimposed our best fit theoretical isochrones.

The uncertainties in the age determination range from 10 ÷ 20%, while the spread of the CMDs reflects in an interval of 1.6 ÷ 2.0 for α_{ms} .

Uncertainties

Theoretical predictions for surface ^{7}Li abundance are quite sensitive to the uncertainties in the chemical composition of the star, besides the age and the mixing length.

• [Fe/H] ; the normal error is extimated to be about 0.05 - 0.1 dex. We adopt an uncertainty on this quantity of Δ[Fe/H] = ± 0.05.

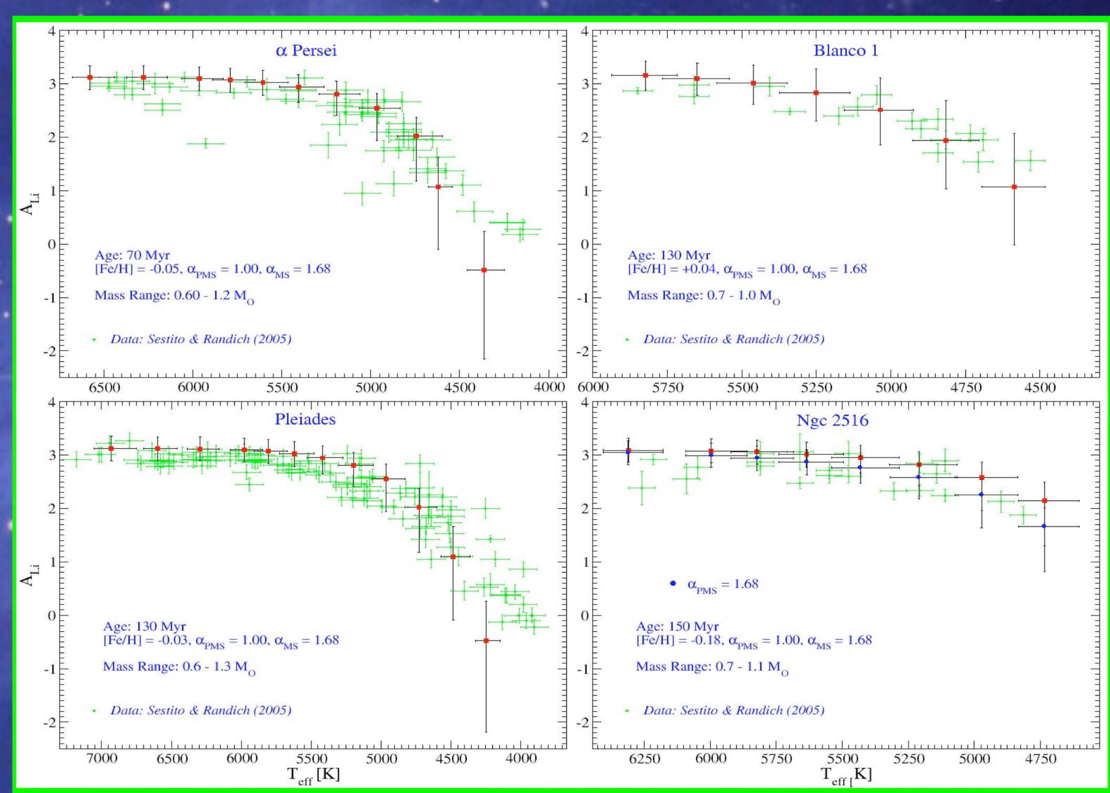
• Primordial abundance of helium (Y_p), and helium to metal enrichment ratio (ΔY/ΔZ). Recent analysis give Y_p ≈ 0.2485 (Peimbert et al. 2007), while older estimates indicate Y_p ≈ 0.230 (Olive et al. 1991). The generally adopted values for ΔY/ΔZ range between 1 ÷ 5. We computed our models adopting Y_p = 0.248, ΔY/ΔZ = 2 and an uncertainty on Y of ±0.015 as suggested also by Bahcall (2005).

Lithium Abundances: Results

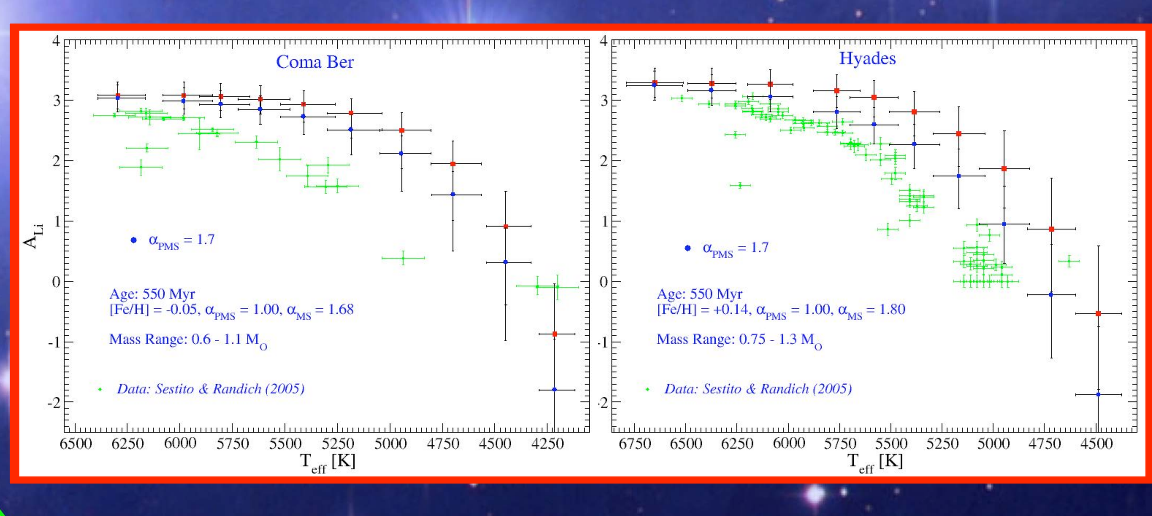
Observational data for ^{7}Li abundance in clusters are taken from the homogeneous analysis by Sestito & Randich (2005), which spans a wide range of ages and chemical compositions.

We found a good agreement between predictions and observations for ^{7}Li abundance in young clusters (ages lower than 150 - 200 Myr), adopting an α_{pms} value lower than the one required to fit the main sequence CMD. The suggested range of α_{pms} is $1.0 < \alpha_{pms} < 1.3$. Such relatively low convection efficiency during the pre-MS phase seems to be in good agreement also with those needed to reproduce the radius of some young low-mass binary systems (Simon et al. 2000; Stassun et al. 2004).

Data for ^{7}Li abundances in the selected young clusters (green dots) compared with our theoretical predictions (red dots)



In older cluster, i.e. age > 200 Myr, the largest is the age the worst is the agreement with the models. Data show an evident depletion of ^{7}Li also during the main sequence phase, which cannot be reproduced by adopting standard mixing (convection), or diffusion, even within the theoretical uncertainties. This may indicate the presence of extra mixing acting on time scales larger than the ones typical of pre-MS evolution.



As in figure 2, but for Coma Ber and Hyades (ages ≈ 550 Myr)

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