# Lithium Abundance and Rotation in the Pleiades and M34 Open Clusters

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**Abstract.** K-type stars of similar effective temperatures in clusters younger than about 250 Myrs are characterised by a wide dispersion in lithium abundance whose origin is not understood.

Photometric monitoring programs indicate that young stars tend to group into two main populations that lie on narrow sequences in diagrams where the measured rotation periods of the members of a stellar cluster are plotted against their (B - V) colours.

I report on the results of a study that investigated the dependence of lithium abundance with effective temperature distinguishing stars that belong to different rotation sequences in the Pleiades and M34 open clusters.

## 1. Introduction

Photometric monitoring programs have produced a large number of rotation period measurements in open clusters, including the Pleiades (Hartman et al. 2010) and M34 (Meibom et al. 2011). These measurements have shown (Barnes 2003) that members of young stellar clusters tend to group on narrow sequences in diagrams where the measured rotation periods are plotted against masses or $B-V$ colour indices. I revisited the connection between Li abundance and rotation in the Pleiades and M34 open clusters in light of these new rotationrate measurements (Gondoin 2014).

## 2. Li abundances and stellar rotation periods measurements

### 2.1 The Pleiades

Recently, Hartman et al. (2010) conducted an extensive photometric time-series survey of the Pleiades based on the membership list of Stauffer et al. (2007). Rotation periods were measured on 368 stars with $0.4 \leq M/\mathrm{M}_{\odot} \leq 1.3$. I cross-matched these data with lithium abundance measurements in the Pleiades retrieved by King et al. (2000). The colour indices of the resulting 64 sample stars are in the range $0.5 < (\mathrm{B}-\mathrm{V})_0 < 1.33$ which corresponds to late-F, G, and early-K spectral types and to masses between 0.7 and 1.3 $\mathrm{M}_{\odot}$. All these stars have reached the main sequence since their Kelvin-Helmholtz contraction timescales is shorter than their age of about 100−150 Myrs (Stauffer 2010).

### 2.2 The M34 open cluster

Lithium abundances in M34 were derived by Jones et al. (1997) from a high resolution spectroscopy study of stars with high membership probabilities. I correlated these data with the list of 83 kinematic and photometric late-type M34 cluster members with known rotation periods established by Meibom et al. (2011), with the results of a time series photometric survey of M34 reported by Irwin et al. (2006), and with the list of 55 solar-type stars in M34, whose rotation periods were derived from differential photometry by James et al. (2010). In total, 23 stellar members of the M34 open cluster have been found that have known rotational periods and Li abundances. Their colour indices in the range $0.55 < (B-V)_0 < 1.23$ and age estimate between 177 Myrs (Meynet et al. 1993) and 251 Myrs (Ianna & Schlemmer 1993) indicate that these stars have reached the main sequence.

## 3. Analysis

### 3.1 Classification into rotation sequences

Observations of main sequence stars with G and K spectral types in young open clusters (∼ 100-200 Myrs) show clear evidence for two distinct sequences of fast and slow rotators in period vs mass or $(B-V)$ colour index diagrams (Hartman et al. 2010). These rotation sequences are called hereafter the C and the I sequence along the paradigm advanced by Barnes (2003).

Figure .1 (bottom) plots the rotational periods $P$ of the M34 sample stars as a function of their reddening corrected $(B-V)_0$ indices. It also displays functional forms of the I and C sequences that were first introduced by Barnes (2003). For the I sequence, I used the form subsequently modified by Barnes (2007) in line with the gyrochronology analysis of M34 performed by Meibom et al. (2011). From the data point positions relative to these curves, the M34 sample stars were classified as lying on the C sequence, on the I sequence, or in the gap between these two sequences.

Hartman et al. (2010) compared the mass-period diagrams, which are equivalent to colour-period diagrams, of the Pleiades and four other open clusters with similar ages. They noted that the mass-period diagram of the Pleiades is remarkably similar to that seen by Meibom et al. (2009) for the M35 open cluster which gyro-age ranges from 134 Myrs to 161 Myrs. Figure .1 (top) shows the colour-period diagram of the Pleiades sample stars with known Li abundances. It also displays functional forms of the I and C rotation isochrones derived from the gyrochronology analysis of M35 performed by Meibom et al. (2009). I classified the Pleiades sample stars as members of the C sequence, of the I sequence or of the gap based on their proximity to the 125 Myrs C and I isochrones.

Four stars in the Pleiades and one star in M34 with $(B-V)_0 < 0.7$ could not be classified and are marked by crosses in Figure .1. These blue and bright objects are most likely close binaries in which the active component is locked into high rotation by synchronisation with the orbital period due to tidal effects.

### 3.2 Lithium abundance and rotation

The lithium abundances of the Pleiades and M34 sample stars are plotted as a function of their effective temperatures in Figure .2. The lithium abundance decreases with effective temperature by nearly three orders of magnitude between 6000 K and 4000 K. This well-known decay is expected from standard models of stellar evolution that predict the attrition of Li as a function of stellar

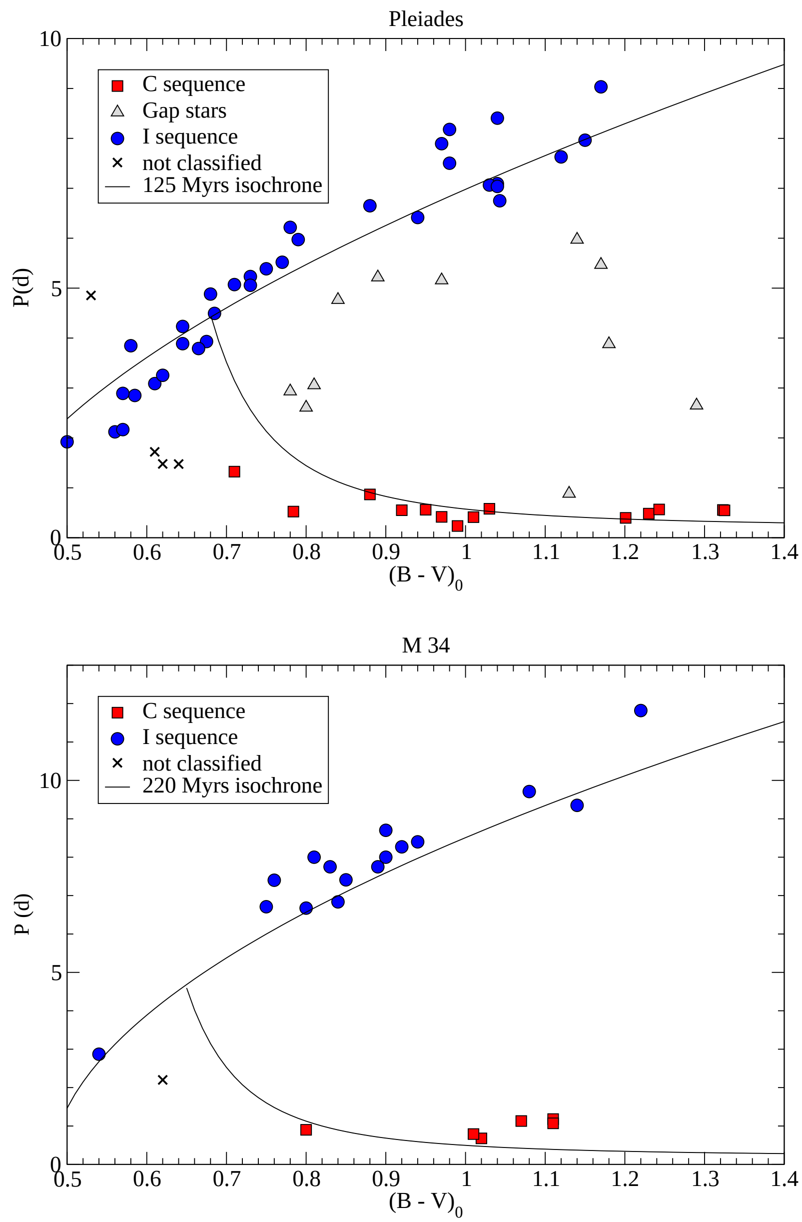


Figure .1: Rotation periods of the Pleiades (top) and M34 (bottom) sample stars as a function of their $(\mathrm{B-V})_0$ colour indices compared with C and I isochrones.

mass, and age. According to these models, pre-main sequence stars with low masses evolving down the Hayashi track develop high enough temperatures at the base of their convection zone for energetic protons to destroy Li there, thereby depleting their surface Li abundance. Reversely, little Li depletion is expected for stars reaching the zero-age main sequence (ZAMS) as A, F, or G dwarfs (Pinsonneault 1997). Since Li depletion ceases as the surface convection zone recedes toward

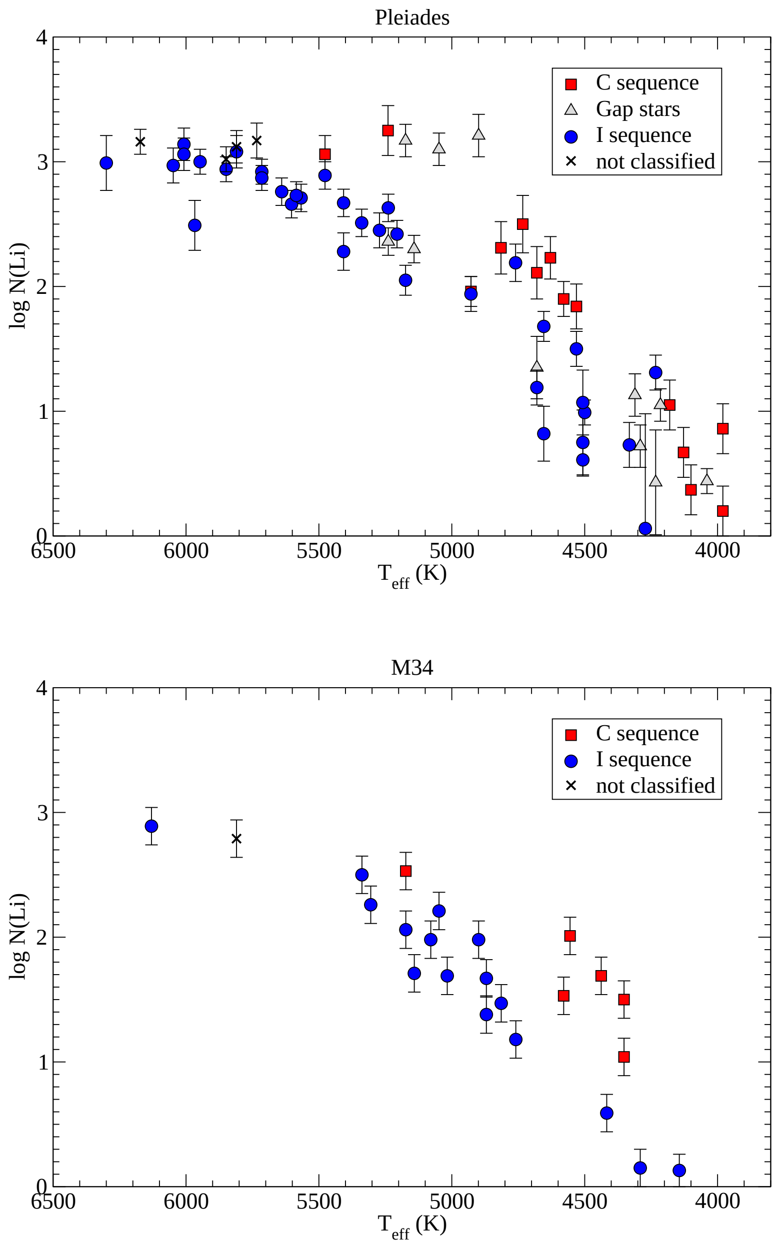


Figure .2: Lithium abundance vs effective temperature for the Pleiades (top) and M34 (bottom) sample stars.

the surface and its base cools, standard models of stellar evolution also predicts that no further Li depletion occurs on the main-sequence for A, F, and G dwarfs (Proffitt et al. 1989); (Deliyannis et al. 1990); (Swenson 1990), whereas K and M dwarfs should continue to deplete Li as they evolve beyond the ZAMS. This prediction is consistent with Figure .2. Indeed, G-type stars have similar Li abundance in the Pleiades and M34 while K-type stars have in average lower Li abundance in the older M34 cluster. This comparison is justified since the two clusters have similar metallicities (Schuler et al. 2003); (Taylor 2008).

However, standard models also predict that $^7$Li depletion in a star is a unique function of age, mass, and metallicity. Figure .2, in contrast, shows that stars with the same $T_{eff}$ in the Pleiades or in M34 have significantly different Li abundances. The scatter in the star-to-star Li abundance is particularly large in the 5500−4000 K temperature range as noted by Jones et al. (1997) in M34 and by Soderblom et al. (1993a), Jones et al. (1996), and King et al. (2000) in the Pleiades. A comparison of the observed scatter in Li abundances with the estimated uncertainties indicates that this spread is statistically significant. Furthermore, Figure .2 shows that, at any given temperature below 5500 K, C sequence and gap stars in the Pleiades have significantly higher lithium abundances than I sequence stars with the same effective temperature.

## 4. Discussion

Independently from any specific model of stellar rotation evolution, the clustering of young main-sequence stars into fast and slow rotation sequences in period vs colour index diagrams, their later evolution through the gap towards a single sequence, and the low density of stars in the gap indicate that stars spend less time in this part of the diagram than on the C and I sequences. The transition from the C to the I sequence thus constitutes an evidence for a brief phase of strong surface rotation deceleration among rapidly rotating late-G and K type stars in their early phase of evolution on the main sequence.

The fact that the transition from the C to the I rotation sequence in the Pleiades and M34 is correlated with a drop in Li abundance suggests that the associated decay of the rotation rate is accelerating the depletion of lithium in young late-G and K-type stars. Rotational braking by stellar winds is the commonly accepted explanation for the decay of stellar rotation on the main sequence. Since the magnetic field lines that sling charged particles from the wind into space are rooted in the photosphere, the wind torque is expected to decelerate the envelope rotation while the conservation of angular momentum should keep the radiative core in rapid rotation. Gap stars in young open clusters should thus develop a large shear at the base of their convection zone that triggers various instabilities. Studies indicate that these instabilities drive mass motions or gravity waves that redistribute angular momentum and mix the stellar material enhancing light-element depletion (Chaboyer et al. 1995); (Charbonnel & Talon 2005); (Talon 2008).

The dispersion in surface Li abundance observed among K stars in young open clusters could thus result from an acceleration of the Li depletion in rapidly rotating K stars due to shear instabilities at the bottom of the convection zone during a brief episode of strong rotational braking by stellar wind in their early evolution on the main sequence. This scenario explains that no lithium dispersion is observed in the Hyades and Praesaepe star clusters (Soderblom et al. 1993b) since, by the age of these clusters ($\sim$ 700 Myrs), observations show a clear convergence in the angular momentum evolution of all F, G, and K dwarfs towards a single sequence of slow rotators. All the stars have by then experienced a strong rotational braking that accelerated Li depletion and the coolest stars ($T_{eff} < 5000$ K) have fully depleted their lithium.

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