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The age of the Hyades from the lithium depletion boundary

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Abstract. The determination of the observational limit below which the cores of very-low mass objects do not reach high enough temperatures and pressure for lithium destruction is called the lithium depletion boundary (LDB). Up to now, the LDB has been used to derive ages of several open clusters younger than 200 Myr, age considered as the practical upper limit of that method. Here we report on the LDB age of the Hyades, demonstrating that this method can be extended to significantly older ages. We obtained intermediate-resolution optical spectroscopy of seven Hyades L dwarf members with the 10.4-m Gran Telescopio de Canarias. We report a clear detection of lithium in absorption at 670.78 nm in the three coolest and least massive members classified as L3.5–L5.0, whose effective temperatures and luminosities are below 1800 K and −4.0 dex, respectively. We derive a LDB age of 650±70 Myr for the Hyades comparing observational constraints with the state-of-the-art BT-Settl models, in agreement with estimates derived from other methods.

Key words. Stars: abundances – Stars: brown dwarfs – Stars: low-mass – Galaxy: open clusters

1. Introduction

The age of open clusters is usually determined from the isochrone fitting of their upper main-sequence members (e.g. Maeder & Mermilliod 1981; Mermilliod 1981). The lithium depletion boundary (LDB) technique is a method proposed for dating open clusters based on a determination of the lithium abundances of a cluster's stars whose masses are at about the hydrogen-burning mass limit. This LDB represents an alternative and completary technique to the isochrone fitting method. Up to now, the LDB has been applied mainly to open clusters younger than 200 Myr, including the Pleiades (125±8 Myr; Stauffer et al. 1998; Barrado et al. 2004), Alpha Persei (85±5 Myr; Barrado et al. 2002, 2004), IC2391 (50±5 Myr; Barrado et al. 1999, 2004), NGC2547 (35±4 Myr; Jeffries et al. 2003; Oliveira et al. 2003), IC4668 (28±5 Myr; Manzi et al. 2008), IC2602 (46±6 Myr; Dobbie et al. 2010), Blanco 1 (132±24 Myr; Cargile et al. 2010), M35 (∼175 Myr; Barrado et al. 2001). We demonstrate in this contribution that the LDB can also be applied to older open clusters such as the Hyades (Martín et al. 2018a; Lodieu et al. 2018).

2. The Hyades cluster

The Hyades cluster (M25) is the closest stellar cluster to the Sun with a mean distance of 46.38±0.12 pc and a proper motion in the 74–140 mas/yr range (Lodieu et al. 2019). The

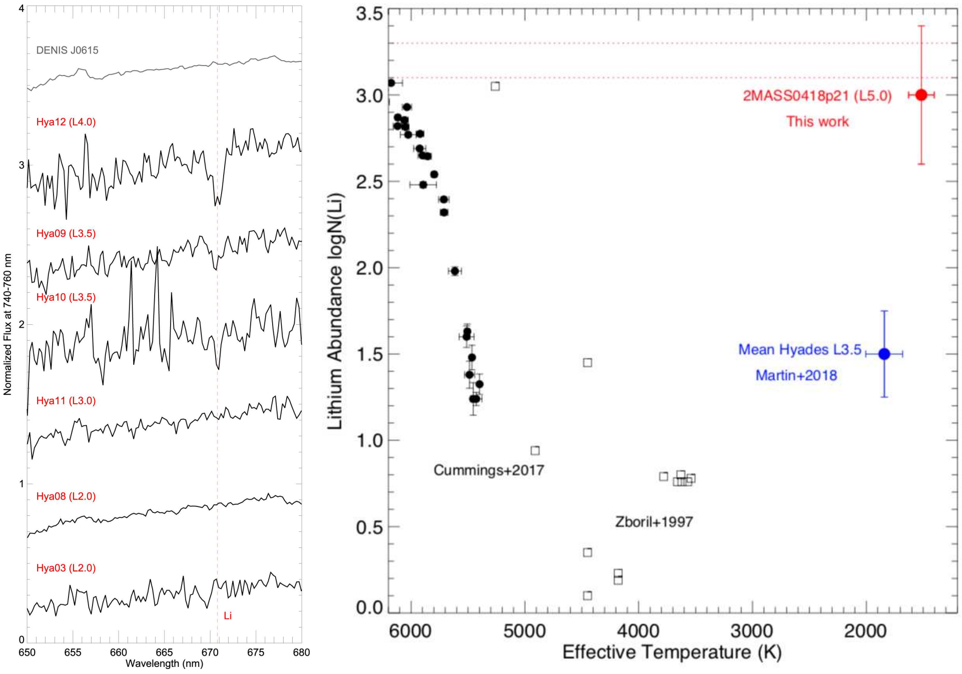

Fig. 1. *Left:* Zoom of the spectral region around the Li resonance doublet at 670.78 nm. The central wavelength of the Li feature is marked with a dashed vertical line. *Right:* Lithium abundances (in the scale of log N(H) = 12) vs effective temperatures for Hyades solar-type stars (black dots; Cummings et al. 2017), K5–M4 stars (upper limits; Zboril et al. 1997), the mean value for L3.5 members (blue dot; Martín et al. 2018a), and the 2M0418 (red dot; Lodieu et al. 2018). The range of initial lithium meteoritic content is shown with red dotted lines as an upper limit of the possible content in substellar atmospheres.

core radius of the cluster is approximately 3.0 pc while its tidal radius is about 9 pc (Perryman et al. 1998; Röser et al. 2011; Lodieu et al. 2019). The reddening towards the cluster is negligible (E($B-V$) ≤0.001 mag; Taylor 2006).

The metallicity has been subject to debate with either a mean metallicity close to solar (Fe/H = 0.05±0.05; Gebran et al. 2010) or a slightly super-solar between 0.127±0.022 dex and 0.14±0.10 dex (Boesgaard et al. 1990; Cayrel de Strobel et al. 1997; Grenon 2000).

Numerous wide-field and deep pencil-beam surveys have focused on the Hyades because it is the nearest cluster to the Sun, see Röser et al. (2011), Goldman et al. (2013), and Lodieu et al. (2019) and references therein for a complete census.

3. Li observations

Hogan et al. (2008) announced several L dwarf member candidates in the Hyades from a cross-match between UKIDSS and 2MASS, using both photometry and proper motion criteria. Casewell et al. (2014) and Lodieu et al. (2014) confirmed 10 of the 12 L dwarf candidates with optical and/or near-infrared spectroscopy. Our group has also discovered a mid-L dwarf candidate, 2M0418 from a search in 2MASS and WISE (Pérez-Garrido et al. 2017). We obtained higher quality optical spectra with the OSIRIS instrument on the 10.4-m Gran Telescopio de Canarias to look at the presence of lithium in absorption at 670.78 nm, an indicator of substellarity in low-mass objects. We find that Hyades members with spectral types earlier than or equal to L3 do not show a clear absorp-

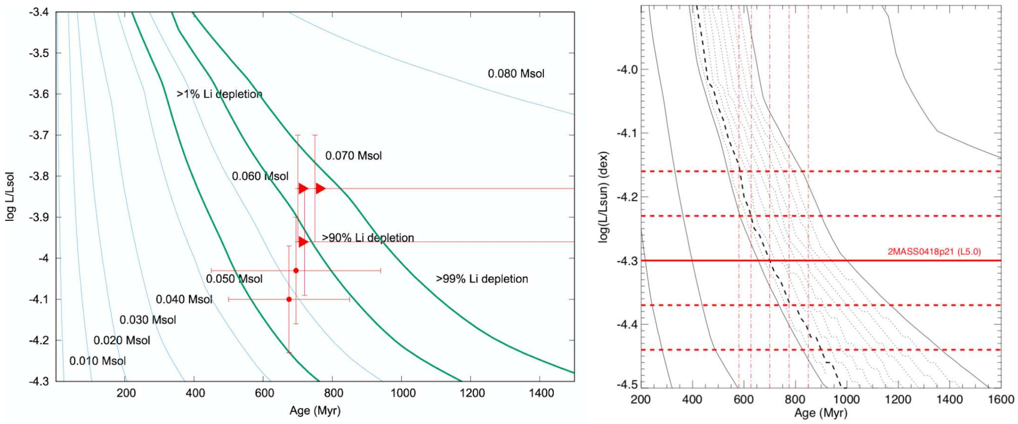

Fig. 2. *Left:* Evolutionary tracks for very low-mass stars and brown dwarfs as a function of age from Baraffe et al. (2015). Masses and predicted Li depletion factors are labeled. The locations of the Hyades L dwarfs are shown. *Right:* Teff vs age of isomasses from the BHCA95 models for masses of 10–80 M_{Jup} by steps of 1 M_{Jup} (black lines). The 51–59 M_{Jup} isomasses are highlighted with black dotted lines for a limited age range (400–1400 Myr).

tion of lithium at our resolution (R∼500) and signal-to-noise while later types do exhibit an absorption at 670.78 nm (Fig. 1). We conclude that the stellar/substellar transition occurs at an effective temperature of about 1800 K and a luminosity of $\log(L_{bol}/L_{\odot}) = -4.0$ dex (Fig. 2).

4. The age of the Hyades

We have transformed the pseudo-equivalent widths of Li into abundances by comparison with predictions from models (Lodieu et al. 2015) and scaling the upper envelope of Li detections in L dwarfs (Kirkpatrick et al. 2000, 2008; Cruz et al. 2009; Lodieu et al. 2015). We assumed an original lithium elemental abundance A(Li) = 3.28±0.05 in the solar system from the study of chondritic meteorites (Lodders 2003). The comparison of our abundances with this upper limit gives an estimate of the amount of depleted Li in the spectra of the Hyades L dwarf members.

Evolutionary models predict the percentage of depletion for a given bolometric luminosity, effective temperature of an L dwarf, allowing us to determine its age and mass, or place lower limits on them in case of non detections. We compared our depletion factors to the predictions of the BT-Settl models (Baraffe et al. 2015) in several diagrams involving effective temperatures and luminosities (Fig. 2). We inferred a mean age of 650±70 Myr for the Hyades from the absence and presence of Li in L dwarf members.

In the past, the age of the Hyades has been often quoted as 625±50 Myr from isochrone fitting with convective overshooting (Maeder & Mermilliod 1981; Mermilliod 1981; Mazzei & Pigatto 1988). Similar ages have been derived from fitting the white dwarf sequence of the cluster (648±45 Myr; de Gennaro et al. 2009; Lodieu et al. 2019) and the study of stellar binaries (∼650 Myr; Lebreton et al. 2001). However, older ages could not be discarded when including enhanced convective overshooting (up to 1.2 Gyr; Mazzei & Pigatto 1988; Eggen 1998; Tremblay et al. 2012) or rotation (750±100 Myr; Brandt & Huang 2015). Our estimate is in agreement with the canonical age of the Hyades but discard ages older than 800 Myr.

5. Conclusions

We have presented optical spectra of several L dwarf members of the Hyades open cluster straddling the hydrogen-burning limit. We find that L3 dwarfs do not exhibit lithium in absorption at 670.78 nm while later types do, placing the stellar/substellar boundary at about 1800 K. We infer an LDB age of 650±70 Myr for the Hyades, in agreement with previous studies within the error bars.

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