W IY N Open Cluster Study: Lithium in Cool Dwarfs of the M35 Open Cluster

David Barrado y Navascués
Max-Planck-Institut für Astronomie, Heidelberg, Germany

Constantine P. Deliyannis
Astronomy Department, Indiana University, USA

John R. Stauffer
Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

Abstract. We have obtained high resolution spectra of \( \sim 40 \) members of M35, determined the Lithium-T\(_{\text{eff}}\) morphology and the distribution of the rotational velocity for G and K stars, and compared them to those of the Pleiades and other well-known open clusters.

1. The cluster background

M35 (NGC 2168) is a very interesting open cluster for several reasons. It is relatively nearby, with \((m-M)_0 = 9.7\) (Vidal 1973). It is very well populated, with a total mass estimated between 1000 and 3000 M\(_{\odot}\). While M35 is at fairly low galactic latitude \((l = 186.58, b = 2.19)\), the cluster is rich enough so that it is easy to separate the field stars and the cluster population. At the same time, the reddening is not very high – \(E(B-V) = 0.17\), (Vidal 1973). Finally, it has been considered a coeval cluster to the Pleiades, since their turn-off points are located at the similar position on the color-magnitude diagram. The traditional age of the Pleiades is 70-100 Myr.

2. The selection of members.

We selected cluster member candidates based on the position of the \([V,(V-I)_{\text{C}}]\) color-magnitude diagram (see Barrado y Navascués et al. 1999). The magnitude interval was \(14.5 \leq V \leq 17.5\), whereas the color range was \(0.8 \leq (V-I)_{\text{C}} \leq 1.6\). Since M35 is very close to the galactic plane, we expect some contamination by field stars. In fact, there is not a clear gap between the locus of the M35

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1Visiting WIYN Observer. The WIYN Observatory is a joint facility of the University of Wisconsin-Madison, Indiana University, Yale University, and the National Optical Astronomy Observatories.
MS and field stars. This smooth transition indicates that a list of photometrically selected candidates of M35 should contain a significant number of spurious members. Subsequently, our member candidates were observed spectroscopically using WIYN/HYDRA, a multifiber spectrograph, capable of observing 97 targets simultaneously at R~20,000 (as measured in the comparison lamps, ~2 pixels). We took 6 individual exposures of ~2 hours each, over 2 different nights. After processing and extracting the individual spectra, we added up all of them to create high quality spectra. Final signal-to-noise ratios range from 40 to 160 per pixel. We measured radial velocities (RV) in the final as well as in the individual spectra, using several iron lines around the lithium doublet (LiII6707.8 Å). Using the measured RV, we catalogued our photometric candidate members in three different groups:

- **Probable members:** This group includes the stars with non-variable RV, which value is close to the average of the cluster (38 stars).

- **Probable short-period binaries, possible members:** A significant fraction of our sample presents variability in the RV. Since we only have 6 points, we cannot derive the value of the center of gravity, and we are unable to establish if these stars belong to the open cluster (19 stars).

- **Probable field stars (non-members) or long-period binaries (possible members):** Those stars with an apparent fixed value of RV, very different of the value of the cluster (19 stars).

Figure 1a shows a color-magnitude diagram with all the possible candidates identified with our optical survey which were observed spectroscopically. Probable members are depicted with solid circles, whereas SB and non-members appear as open circles and crosses, respectively. Note that the short-period SB stars represented a third of the probable/possible members of M35. By comparison, Praesepe has ~40% of SB. Therefore, we expect some of these SB stars to be cluster members.
Figure 2. a Li equivalent widths. Other panels, Li-Teff plane: b Comparison with the Pleiades, c the Hyades, d NGC2516.

3. The relation Lithium–Teff–Rotation

We have measured the projected rotation velocities and compare with their distribution in the Pleiades (Figure 1b) –Pleiades data from Soderblom et al. (1993). Contrary to what happens in the Pleiades, M35 lacks fast rotators in this color range. Since stars spin-down with age, M35 could be older than the Pleiades. However, the difference in the distribution of the rotational velocity also could be due to the initial conditions. Li abundances –A(Li)– were derived from the LiI6708Å equivalent widths (W), taking into account the FeI6707.4Å line, and using curves of growth from Soderblom et al. (1993). Comparison between M35 and the Pleiades shows that although the shape of the dependence of the W(Li) with color is quite similar, the M35 values are systematically smaller and the scatter for a given color is also reduced (Figure 2a). The Li-Teff plane is depicted in Figures 2b,c,d. Panel b shows the Pleiades, Panel c displays the Hyades (see Barrado y Navascués & Stauffer 1996 and references therein), and Panel d contains NGC2516 data (Jeffries et al. 1998). Three main studies have been carried out concerning the relation between the spread in the Li abundance
and rotation-activity in the Pleiades open cluster (Soderblom et al. 1993; García-López et al. 1994; Jones et al. 1996). All these three works concluded that Pleiades stars present an intrinsic scatter in their abundances for the same color and connected the differences with stellar activity and rotation (the higher the activity, the faster the rotation and the Li abundance for a given color). In the case of M35, we do not see a dramatic scatter in the Li abundance, at least in the range 6000>Teff>4600. Below that temperature, a more important scatter is present. However, only two stars have an abundance notably higher than the average trend. In this color range, a connection between rotation and Li might be present, since the only obvious fast rotator (42 km/s) is clearly a Li–rich M35 star. Finally, the average M35 Li abundance for a given color is systematically smaller than the average Pleiades Li abundance. The comparisons with other open clusters, such as the Hyades and NGC2516 (Panels c and d) indicate that, in fact, M35 could be as old as this last one, based on the morphology of the dependence of Li with effective temperature, if we assume that age is the single most important parameter for Li depletion in cool dwarfs (see Deliyannis 1999).

4. Conclusions.

We have detected a significant number of late spectral type members of the M35 open cluster based on optical photometry and high resolution spectroscopy and derived Li abundances for our M35 members. We have compared their distribution with Pleiades stars. Contrary to what happens in the Pleiades, M35 does not show a significant scatter in the Li-Teff plane for dG and early dK stars. The derived abundances are systematically smaller. On the other hand, the distribution of vsini are also different in both clusters, with M35 lacking fast rotators; a connection between rotation and Li abundance might be present in late dK members of M35. Therefore, M35 seems to be older than the Pleiades, perhaps as old as NGC 2516 (140 Myr), which agrees with resent results (von Hippel et al. 1999; Sung & Bessel 1999).

Acknowledgments. DByN thanks the IAC (Spain) and the DFG (Germany) for their fellowship, and the support by the European Union.

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