A Lithium Age for the Young Cluster IC 2391

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Abstract. We have identified a large number of possible very low mass members of the cluster IC 2391 based primarily on their location in an $I$ versus $(R-I)_C$ CM diagram. We have obtained new photometry and low resolution ($\Delta \lambda = 2.7$ Å) spectroscopy of 19 of these objects ($14.9 \leq I_C \leq 17.5$) in order to confirm cluster membership. We identify 15 of our targets as likely cluster members based on their spectral types, radial velocity, EW(NaI8200 Å), and Hα emission strengths. One of these stars has a definite lithium detection and two other (fainter) stars have possible lithium detections. We find the lithium depletion boundary in IC 2391 is at $I_C=16.2$, which implies an age for IC 2391 of $53 \pm 5$ Myr. While this is considerably older than the age most commonly attributed for this cluster ($\sim 35$ Myr), the correction factor to the IC 2391 age is comparable to those recently derived for the Pleiades and $\alpha$ Per clusters and can be explained by new models for high mass stars that incorporate a modest amount of convective core overshooting.

1. Observations

At a distance of $\sim 155$ pc and with a canonical age of $\sim 35$ Myr, IC 2391 is an ideal candidate to obtain an age based on the lithium depletion boundary (LDB). This method is claimed to be less subject to possible systematic errors than those based on isochrone fitting to the upper main sequence (Ventura et al. 1998a,b). See Stauffer (1999, these proceedings) for more details about the LDB method. We have carried out several observing campaigns to identify new very low mass members, based primarily on their photometric properties, and to confirm membership and the location of the LDB, via spectroscopy.

Photometry: (i) “Big Throughput Camera” at the 4m/CTIO (Jan 1998). We covered 2.5 sq. deg. in the $R_I$ filters, reaching a limiting $I_C=23$, (ii) 0.9m/CTIO + $VIZ$ filters (April 1998 and Jan 1999), (iii) Additional $JHK$ photometry from 2MASS project (Adams 1998, priv. com). In total, we iden-

1 Visiting Astronomer, CTIO, operated by AURA, Inc. under cooperative agreement with the National Science Foundation
tified 126 candidate members located in the cluster loci in all CM and CC diagrams.

**Spectroscopy:** CTIO 4m/RC spectrograph, Jan 1999 (6300-8820 Å, 2.7 Å resolution. We observed 19 IC 2391 candidate members, as well as several field M dwarfs for comparison purposes.

Additional details about the photometry and the selection of members can be found in Barrado y Navascués et al. (1999).

2. **The selection of members.**

The LDB age technique requires moderate S/N and spectral resolution. Even for the closest and youngest clusters, the use of 4m class telescopes (or larger) and long exposures times (in the case of IC 2391, up to 4 hours) are necessary. Therefore, it is vital to select the best membership candidates as targets for spectroscopic observations. This is achieved by using CM and CC diagrams (see Figure 1a,b). With spectra in hand (some examples are shown in Figure 2), we used the following criteria to determine the cluster membership status of our candidates:

- Radial velocities were compared with the cluster average of 15 km/s (Stauf-fer et al. 1997).
- \((R-I)_C\) colors were derived by comparing the strength of several pseudo-continuum bands (TiO, VO and CaH) with the values of field stars. These colors were compared with the photometric values, assuming \(E(R-I)_C=0.01\) for IC 2391. The same method was used to derive spectral types.
- The gravity dependent NaI\(8200\) Å doublet (strong in dM, weaker in PMS M, and very weak in M giant stars, Martín et al. 1996) was used to eliminate background giants and nearby field stars.
• Hα equivalent widths were compared with typical values for field stars and Pleiades members (see Figure 3a). This graph indicates that most of our objects are chromospherically very active and, therefore, young.

These criteria allowed us to reject two stars as members of the cluster, and classify another 2 as possible non-members. The other 15 objects are likely members of the IC 2391 cluster. The two faintest members are likely to be brown dwarfs, based on their photometry and theoretical models (D’Antona & Mazzitelli 1997, Chabrier & Baraffe 1997).

3. The lithium depletion boundary and the age of IC 2391.

Lithium was detected in one of the bona-fide members and was possibly detected in two other bona-fide members (Figure 2). Figure 3b shows a CM diagram for our candidates. We indicate those having lithium as well as those members without it. A ZAMS and two isochrones of 30 and 50 Myr are included for comparison (D’Antona & Mazzitelli 1997). We estimate that the location of the LDB is at $I_C=16.2\pm0.15$. Using a distance modulus of $m - M = 5.95 \pm 0.1$ and $A_I=0.02$ yields $M(I)_{LDB}=10.23$. This implies a cluster age of $53\pm5$ Myr, following Figure 3 of Stauffer et al. (1998). Additional details on this result can be found in Barrado y Navascués, Stauffer, & Patten (1999). While this value of the cluster’s age is significantly larger than previous estimates (~35 Myr), our result is consistent with recent age correction estimates of other young open clusters, such as the Pleiades (125±8 Myr, Stauffer et al. 1998) and α Per (90±10 Myr, Stauffer et al. 1999), using the LDB method. The LDB ages for these latter two clusters are consistent with age estimates using upper main sequence isochrone fitting using models which assume a modest amount of convective core overshoot (Ventura et al. 1998a,b). Since the ratio $\text{Age(standard)}/\text{Age(LDB)}$ is almost constant for all these three clusters, it seems that the same moderate
Figure 3. a Hα equivalent widths against the \((R - I)\) color. Bona-fide IC 2391 members are expected to show a relatively high level of chromospheric activity. b CM diagram and the LDB for IC 2391.

amount of overshooting is needed (at least in the mass range of the turn-off of these clusters). The new age scale for young open clusters based on the LDB ages would have important consequences in a large variety of topics, including the empirical and theoretical correlations between lithium abundance, stellar activity, and rotation rate as a function of age for low mass stars.

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