THE EVOLUTIONARY STATUS OF HIGH-LITHIUM, HIGH-ACTIVITY COOL DWARFS

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ABSTRACT. We have used the newly available Hipparcos parallaxes to study the evolutionary status of a number of high-lithium, high-activity late-type dwarfs found in X-ray based surveys, i.e. the *Einstein* Extended Medium Sensitivity Survey and the *Einstein* Slew Survey. The sample stars are placed on evolutionary tracks thus estimating their age.

1. INTRODUCTION

Lithium-rich cool stars have been shown to be common in high Galactic latitude X-ray surveys from the *Einstein* observatory (Favata et al. 1993, 1995), from the EXOSAT observatory (Tagliaferri et al. 1994) as well as in samples from the ROSAT Wide Field Camera survey (Jeffries 1995), selected on the basis of their EUV emission. Such stars do not appear to cluster around known star-forming regions (SFR), thus raising the question of their age and origin. While their relatively high lithium abundance seems to point toward their being quite young, with some of them possibly still in the pre-main sequence phase, the complex picture presented by the available data on lithium evolution in cool stars is such that lithium alone cannot be used as an accurate measure of age.

Optical identification of a number of ROSAT All-Sky Survey (RASS) stellar sources (see for example Alcalá et al. 1995 and the following works) around known star-forming regions (and thus in general at low Galactic latitude) have produced samples of stars with similar characteristics as the stellar samples derived from the high latitude X-ray surveys discussed above. The origin of these potentially very young stars is currently the subject of a debate. If they are still on the Hayashi track, i.e. with ages of a few million years at most, they pose the problem of their origin, as many of them are far from obvious sites of recent star formation. On the other hand, if they are close to the Zero-Age Main Sequence (ZAMS), and thus with ages of tens of million years (perhaps up to 10^8 years), their origin is much less problematic.

The availability of precise parallaxes from the Hipparcos Catalog (ESA 1997) for a number of activity-selected cool dwarfs allows us to accurately place these stars on state-of-the-art evolutionary tracks, and thus determine their evolutionary age.

2. THE SAMPLE

We discuss here a sample of X-ray selected stars (from the *Einstein* Extended Medium Sensitivity Survey, EMSS, and the *Einstein* Slew Survey, ESS). While this sample is not complete, due to the selection criteria of the Hipparcos Input Catalog, it allows useful insight in the characteristics of the EMSS and ESS stellar populations. The biases present in the sample are discussed in detail by Micela et al. (1997). The sample has been divided in three groups. The first group contains the stars which have photospheric lithium abundance (for their spectral type) higher than the typical abundance of field stars. All of these stars also have high activity levels ($L_{\rm X} \geq 10^{28.6}$ erg s^{-1}). These stars, given their lithium abundance, are expected to be 'young', and the aim of the present work is essentially to help qualify the meaning of 'young' in the context of activity selected samples of stars. The second group contains stars (from the same parent sample) with low lithium abundance (i.e. comparable to field stars of the same spectral type). These stars on the average have lower activity levels than the first sub-sample. The third group contains stars for which the lithium abundance is not known, and which do not have any known peculiarity. The sample is presented in Table I. In all cases, we have removed known binaries from the samples.

TABLE I
The sample of X-ray selected stars.

Name	N(Li)	$B-V$	$V-I$	$M_{\rm V}$	$L_{\rm X}$
High-lithium, high-activity sample					
HD 105	3.4	0.60	0.67	4.49	29.2
HD 48189	3.3	0.62	0.69	4.47	29.8
HD 17925	2.9	0.86	0.91	5.97	28.6
HD 36705 (AB Dor)	3.1	0.83	0.94	6.01	30.1
GJ 182	1.8	1.39	1.84	7.92	29.8
Lower-lithium, lower-activity sample					
SAO 63275	1.2	0.85	0.85	6.37	29.6
HD 10360	< -1.0	0.88	0.93	6.21	27.5
SAO 182743	< 0.0	1.08	1.04	6.79	29.1
GJ 698	< -0.2	1.18	1.18	7.41	28.3
Sample with unknown lithium abundance					
HD 80388	–	0.59	0.66	4.75	29.1
HD 155674	–	1.15	1.25	7.22	28.5
GJ 659 B	–	1.26	1.42	7.74	28.5
GJ 900	–	1.33	1.65	8.16	28.7
HIP 48899	–	1.40	1.53	7.77	29.0
HIP 12787	–	1.42	1.67	8.35	29.4

3. RESULTS

The details of the methodology used are given in Favata et al. (1997). In brief, the latest evolutionary tracks from D'Antona and Mazzitelli (in preparation) were used, converted to the $B-V$, $M_{\rm V}$ plane, while the Hipparcos parallaxes and photometry were used to compute the $M_{\rm V}$ of each object in the sample.

The evolutionary HR diagram for the objects in our sample is shown in Figure 1. The high-lithium objects are shown with filled symbols, the lower-lithium ones with empty square symbols, while objects without known lithium abundance are indicated by the crosses.

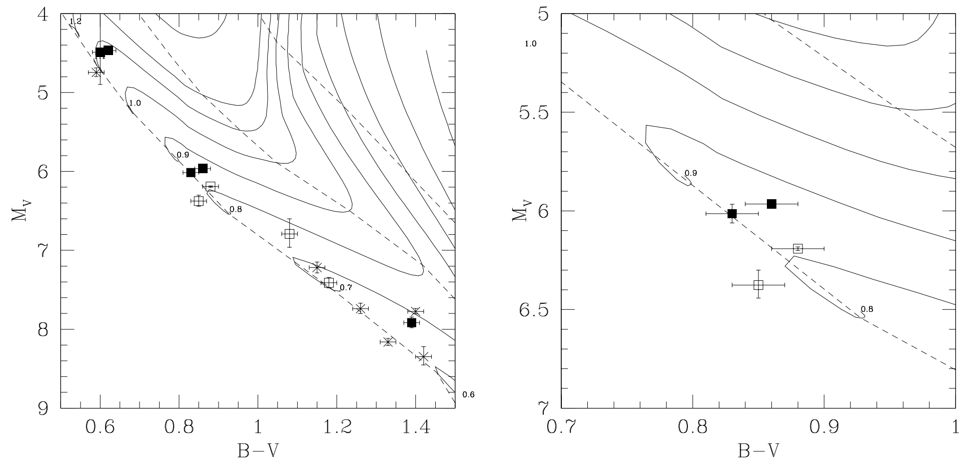

Fig. 1. The evolutionary H-R diagram for the stars in our sample. The continuous lines are the evolutionary tracks at different masses (indicated by the label on the main sequence), while the dashed lines are the isochrones at (going downwards) 10^6, 10^7 and 10^8 yr. The lithium-rich sample stars are indicated by the filled symbols, the lithium-poor stars are indicated by the empty square symbols while objects without known lithium abundance are indicated by the crosses. The right panel shows a zoom on the early-K stars.

While the high-lithium dwarfs in our X-ray selected sample tend on average to be located on slightly younger isochrones with respect to stars in the sample with low lithium and with unknown lithium, there is not a clear separation between the groups.

The two K-type high-lithium dwarfs (two well-known objects, AB Dor and HD 17925) are very close to the main sequence, with AB Dor lying on the nominal 10^8 yr isochrone (i.e. essentially on the ZAMS) and HD 17925 nominally on an isochrone of some 50 Myr. Note however that the $1\,\sigma$ error bars of the age estimates of HD 17925 and AB Dor overlap. Neither of them thus shows any evidence for being a 'pre-main sequence' object in the sense of lying sensibly above the main sequence or of being in a contracting phase. Also, while all the available age indicators would point at HD 17925 being significantly older than AB Dor (it has much lower activity level, rotational velocity and slightly lower lithium abundance), its position on the evolutionary tracks points at its being younger or coeval with AB Dor.

The high-lithium M-dwarf GJ 182 also lies somewhat above the main sequence, on an isochrone implying an age of $\simeq$ 50 Myr. Given its high lithium abundance, very unusual for a field M-dwarf, GJ 182 was expected to be young. However, standard evolutionary models predict that a $\simeq 0.7\ M_\odot$ object should have essentially depleted its lithium already at an age of $\simeq 10^7$ yr, thus raising some questions related to the lithium depletion mechanisms (or alternatively indicating that the nominal evolutionary tracks do not correctly describe the age of GJ 182). HIP 48899 lies very close to GJ 182, but no further optical information is available for this object.

4. CONCLUSIONS

While the coverage of the complete X-ray selected sample observed by the *Einstein* observatory is at best spotty, due to the selection effects present in the Hipparcos Input Catalog, the limited sample for which accurate data are available allows some conclusions to be drawn:

- X-ray selected, lithium-rich solar-type stars are, as expected, young, but not exceedingly so. The objects studied here are, with characteristic ages of ≥ 50 Myr, well past the Hayashi tracks;
- solar-type stars with very similar mass and evolutionary state, can have very different characteristics. HD 17925 and HD 36705 (AB Dor) are on the same evolutionary track and with age estimates overlapping at the 1σ level. Yet they differ widely in terms of lithium abundance, X-ray emission level, and rotational velocity. This shows the danger of attributing individual ages by using 'proxies'. At the same time, however, the recently shown spread in the position of the ZAMS in different open clusters, of up to 0.4 mag, (Mermilliod et al. 1997) introduces an additional, large uncertainty in the age determination of individual stars. So relative age determinations (such as the one for HD 17925 and HD 36705 discussed in the above paragraph) have to be taken with some caution;
- some isolated young red objects are present in the samples studied, although they are well past their Hayashi-track phase. GJ 182, at $\simeq 50$ Myr (with the above caveats) shows a much higher lithium abundance than expected.

References

Alcalá J.M., Krautter J., Schmitt J.H.M.M., et al., 1995, *Astron. Astrophys.* **114**, 109

ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP–1200

Favata F., Barbera M., Micela G., Sciortino S., 1993, *Astron. Astrophys.* **277**, 428

Favata F., Barbera M., Micela G., Sciortino S., 1995, *Astron. Astrophys.* **295**, 147

Favata F., Micela G., Sciortino S., D'Antona F. 1997, *Astron. Astrophys.*, submitted

Jeffries R.D., 1995, *Mon. Not. R. Astr. Soc.* **273**, 559

Mermilliod J.-C. et al., 1997, ESA SP–402, p. 643

Micela G., Favata F., Sciortino S., 1997, *Astron. Astrophys.* **326**, 221

Tagliaferri G., Cutispoto G., Pallavicini R., Randich S., Pasquini L., 1994, *Astron. Astrophys.* **285**, 272