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

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ABSTRACT

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

Key words: Active stars; Stellar populations; Low-mass stars; Stellar ages.

1. INTRODUCTION

Samples of activity-selected stars have been shown to contain a large fraction of cool stars with photospheric lithium abundance higher than the average field population. Such lithium-rich stars are 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 selected on the basis of their EUV emission, from the ROSAT Wide Field Camera survey (Jeffries 1995). These activity-selected lithium-rich stars from wide-field surveys 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 age indicator.

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 Catalogue (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 have used, as starting point, a sample of X-ray selected stars (from the *Einstein* Extended Medium Sensitivity Survey, EMSS, and the *Einstein* Slew Survey, ESS) for which we were granted early-access Hipparcos data. While this sample is not complete, due to the selection criteria of the Hipparcos Input Catalogue, it still 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).

We have extracted, from the full sample of X-ray selected stars three groups. The first sub-sample contains the stars which have photospheric lithium abundance (for their spectral type) higher than the typical abundance of field stars. Use has been made of the Li measurements of Favata et al. (1993, 1995). All of these stars also have high activity levels ($L_X \geq 10^{28.6}$ 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 sub-sample contains stars (from the same parent sample) with low lithium abundance (i.e. comparable to field stars of the same spectral type). These stars all have lower activity levels than the first sub-sample. The third sub-sample contains stars for which the lithium abundance is not known, and which do not have any known peculiarity. The samples are presented in Table 1. In all cases, we have removed known binaries from the samples.

Table 1. The sample of X-ray selected stars.

Name	N(Li)	$B-V$	$V-I$	M_V	L_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
HD 80389	–	1.60	1.21	4.87	29.2

3. METHODOLOGY

We have used the latest evolutionary tracks from D'Antona and Mazzitelli (in preparation), computed for solar metallicity. These tracks cover the mass range 0.02–3.0 $M_\odot$, and follow the evolution of stars all the way from the birth-line into the early post-main sequence phase. They are computed with the latest updates to the input physics, including opacities and convection theory.

The accurate Hipparcos parallaxes, together with the photometry included in the Hipparcos Catalogue, allow the determination of the absolute magnitude with small (and well-determined) error bars. The determination of the effective temperature of the sample stars is problematic, given the uncertainty in the colour-temperature calibrations in the cooler stars as well as the lack of homogeneous photometry for many stars. We have, after some experimenting, decided to use the $B-V$ colour, as available from the Hipparcos Catalogue, as temperature indicator.

While the $V-I$ colour is in principle a better choice in terms of its quasi-independence from metallicity and surface gravity effects in cool stars, the heterogeneous nature of the $V-I$ values provided in the Hipparcos Catalogue, together with the uncertainty in the available transformations from colour to temperature, make it a less appropriate choice in the present context.

The metallicity-dependence of the temperature calibration of the $B-V$ index should contribute to the total uncertainty, in the present sample, only at a modest level, given that the sample appears to have a metallicity close to the solar value. This has been verified, on a randomly selected sub-sample, using spectroscopic data (Favata et al. 1997).

For the purpose of determining the evolutionary status of the sample stars we have converted the evolutionary tracks (which are expressed in the physical space $T_{\rm eff}$, $L_{\rm bol}$) onto the observational plane $B-V$, $M_{\rm V}$. For this, we have used the recent calibration of $B-V$ versus $T_{\rm eff}$ and bolometric correction (BC) as a function of effective temperature of Flower (1996).

The effective temperature and bolometric luminosity for each sample star allow in principle to place it on the evolutionary tracks and determine its evolutionary status with well determined and in general small uncertainty. For example, for a star at 25 pc, the typical uncertainty in the absolute magnitude coming from the uncertainty in the Hipparcos parallax is $\simeq 5$ per cent, or only $\simeq 0.05$ mag. To this uncertainty one has to add the typical statistical uncertainty of the bolometric correction, which typically is $\simeq 0.1$ mag. This translates, for a typical K0 star close to the ZAMS, into a negligible age uncertainty.

The uncertainty in colour is more difficult to assess because, among other things, of the possible influence of star-spots in the more active stars, which would change their 'true' colour in a difficult to determine way. Neglecting this systematic effect, however, the typical uncertainty in the colour is $\pm \simeq 0.02$ mag, which, again for a near-ZAMS K0 star, is equivalent to an uncertainty of $\pm \simeq 10$ Myr.

A much more significant source of uncertainty is the recent evidence, coming from the Hipparcos determinations of cluster distances (Mermilliod 1997), of a large difference in the position in the HR diagram of the main sequence of a number of open clusters. These recent results show that the main sequence of different clusters can have absolute luminosities differing by up to 0.4 mag, in a way apparently uncorrelated with the photospheric metallicity. Such a range in absolute magnitudes at a given colour is likely to be present also in field stars. Given that the evolutionary tracks have been computed assuming the existence of a uni-parametric main sequence, this new observational fact adds a further, large uncertainty to the process of dating individual objects. Under the assumption that the tracks are still valid and that the 'hidden parameter' which causes the shift in the main-sequence position only causes a rigid shift in the tracks, the additional uncertainty has the effect of making it impossible to distinguish a ZAMS K0 star from a star of the same colour but with an age of $\simeq 50$ Myr.

4. RESULTS

The evolutionary HR diagram for the objects in our sample is shown in Figure 1. The horizontal error bars of the different data points are related to the accuracy indicated in the Hipparcos Catalogue for the $B-V$ colour, which for some objects is relatively low, presumably, at least in some cases, because of intrinsic source variability, which is not unexpected in the redder and more active stars. The high-lithium objects are shown with filled symbols, the lower-lithium ones with empty square symbols, while object without known lithium abundance are indicated by the empty circles.

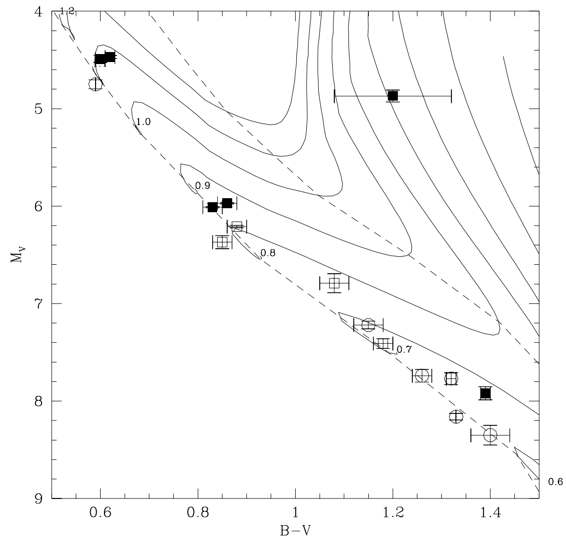

Figure 1. The evolutionary HR diagram for the stars in our sample. The continuous lines are the evolutionary tracks at different masses (indicated by the label on the main sequence), while the dashed lines are the isochrones at (going downwards) 10^7 and 10^8 yr. The lithium-rich sample stars are indicated 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 empty circles. For HD 80389 (the only object on the Hayashi tracks) the B–V colour is derived from the V–I colour.

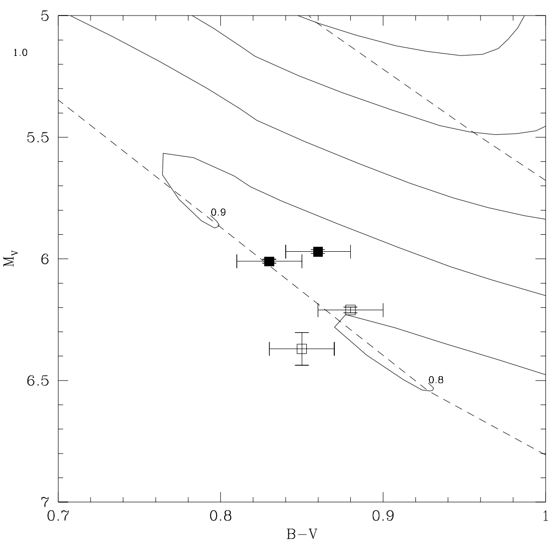

Figure 2. An enlargement of the evolutionary HR diagram for the stars in our sample, focusing on the early K stars. The continuous lines are the evolutionary tracks at different masses (indicated by the label on the main sequence), while the dashed lines are the isochrones at (going downwards) 10^7 and 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.

5. DISCUSSION

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 (but with error bars overlapping with AB Dor). 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 their being coeval.

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).

The only object in the sample with indication of extreme youth is HD 80389, an otherwise unknown M2 star (never quoted in the literature), whose position in the colour-magnitude diagram implies a nominal age of only $\simeq$ 2 Myr. Its available colours are somewhat inconsistent, with the $B-V$ colour implying a very red object, too red for its absolute magnitude. The temperature derived from the $V-I$ index appears more 'realistic', and it has been scaled back to the $B-V$ index for positioning the object on the evolutionary tracks. Such anomalous colours could be indicative either of heavy reddening or of a peculiar spectrum. Given its position in a region of sky far from known SFRs, HD 80389 deserves further study.

6. 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 Catalogue, 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 $\gtrsim$ 50 Myr, well past the Hayashi tracks (with a single exception, HD 80389);

- 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';

- the recently shown spread in the position of the ZAMS makes the age determination of individual objects using their position on uniparametric evolutionary tracks much more uncertain than previously thought. The observed spread of up to 0.4 mag in the main sequence luminosity could produce an uncertainty of a factor of $\simeq 2$ for a K0 star close to the ZAMS. This implies that relative age determinations (such as the one for HD 17925 and HD 36705 discussed in the above paragraph) have to be taken with caution;

- some isolated, rare young red objects are present in the samples studied. GJ 182, at $\simeq 50$ Myr (with the above caveats) shows a much higher lithium abundance than expected, while HD 80389, at only $\simeq 2$ Myr (i.e. a PMS still in its contracting stage) with its position far from known star-forming regions, is a puzzling object.

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