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Age determinations of main-sequence stars: combining different methods

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Abstract. We have determined the age of a sample of nearby main-sequence stars with spectral types B9–K9. We have derived the stellar ages from five different age estimators: the location in the HR diagram compared to theoretical isochrones, the rotational velocity, the strength of chromospheric calcium emission lines, the stellar metallicity, and their space velocity. New calibrations consistent with recent theoretical isochrones are provided for the last four indicators. For hot stars, isochrones are the best indicator, while stellar rotation is best for cool stars. However, many stars require in fact a combination of different methods to properly bracket their actual age. We also discuss the uncertainties involved, in particular those in using isochrones, and we find that these uncertainties are often underestimated in the literature.

Key words: stars: activity – stars: chromospheres – stars: evolution – stars: rotation

1. Introduction

Recently, we needed to determine the age of a sample of isolated, nearby main-sequence stars. These stars have been observed by the *Infrared Space Observatory* to look for circumstellar debris disks similar to the disk found around Vega. It is of particular interest to establish whether or not the presence of a circumstellar disk depends on the age of the star.

The age of main–sequence stars may be estimated in various ways, and no single method is applicable to all stars. The existing literature on the age determination is surprisingly sparse – most articles concentrate on one special method or on groups of stars of the same age, e.g. associations or clusters. In this paper, we hope to fill a gap by discussing and comparing the different methods of estimating the age of main-sequence stars.

We have used the following age estimators: *(i)* the luminosity of the star with respect to its zero-age main-sequence luminosity; *(ii)* the stellar rotation; *(iii)* the stellar activity; *(iv)* the space motion of the star; and *(v)* the metallicity of the star. In many cases, only an upper or lower limit to the age can be derived by a given method due to uncertainties. It is therefore necessary to use several estimators to properly bracket the actual stellar age.

In Sect. 2, we briefly discuss the different methods and how they are calibrated. We pay special attention to errors. They have two sources: uncertainties in the observed properties of the star and systematic errors of the method. The systematic errors include uncertainties introduced by the calibration. We attempt to properly derive the uncertainties that enter via the observed quantities of the stars, and we quote the uncertainties given in previous papers on age determination. As we shall show, the errors have often been considerably underestimated in the past.

Even though some age estimates exist for part of our sample, we have repeated the analysis in the light of new theoretical isochrones by Bertelli et al. (1994) which yield different ages (Ng & Bertelli, 1998, hereafter NB98). For the other methods, we have updated the calibrations in order to make them consistent with the new isochrone ages.

We give the results from the different methods as a median age, and with 67% uncertainty limits (the probability of the actual age to be between the median value and either the lower or upper limit is 33.5%). If the probability distribution were Gaussian, these limits would thus correspond to one-σ errors.

2. Five age estimators

2.1. Isochrones

When main-sequence stars evolve off their ZAMS (Zero-Age Main-Sequence) position, their luminosity slowly increases while their effective temperature also changes. The position in the HR diagram may thus be used to determine the age of the star. Obviously, this method works better for stars that evolve more rapidly, i.e. the early-type stars. One needs theoretical isochrones in the HR diagram and some stellar data: the absolute magnitude, M_v, the effective temperature, $T_{\rm eff}$, and the metallicity, $[{\rm Fe/H}]$. Because all our stars are within 25 pc, good-quality measurements of these parameters are generally available in the literature with only very few exceptions.

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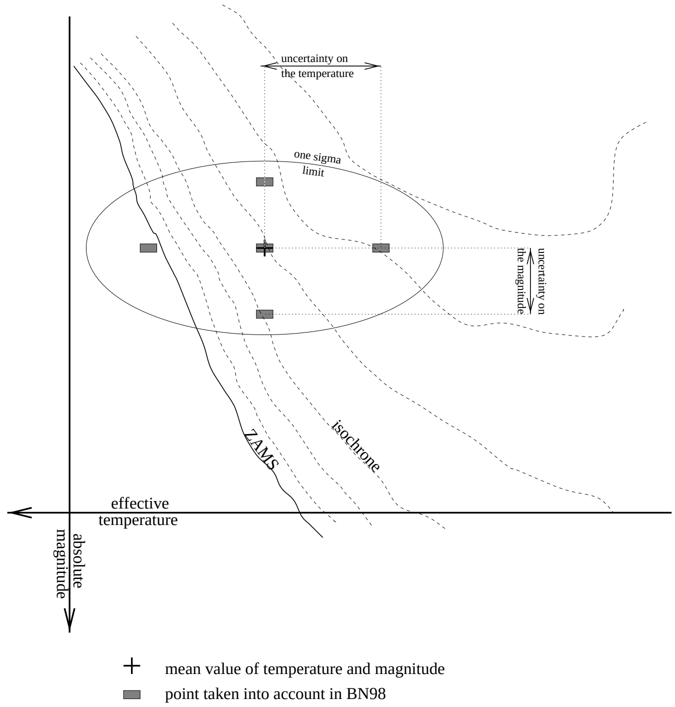

Fig. 1. The shape of the isochrones in the HR diagram. The ellipse denotes the one-σ range of the observational errors. The squares are the locations where NB98 sample the distribution to determine the age uncertainty. Note the asymmetric distribution of the isochrones around the median age.

We used Bertelli et al.'s (1994) recent set of isochrones. For ages from $10^{6.6}$ to $10^{10.3}$ years, their tables list the stellar mass, $M_\star$, the effective temperature, $T_{\rm eff}$ and the magnitudes for different standard filters. The tables are available for 6 different metallicities, ranging from $[{\rm Fe/H}] = -1.4$ to $[{\rm Fe/H}] = +0.4$. For each star of our sample, we constructed first a table of M_v and $T_{\rm eff}$ for the measured value of $[{\rm Fe/H}]$ by interpolation between tables of different metallicities. This interpolation was however often not practicable because there is no straightforward overlap between isochrones for different metallicities. Let us consider as an example two stars of same mass and age, but different metallicity. Due to the difference in metallicity, one star may still be on the main-sequence, while the other may already be on its way to the giant branch. A simple, direct interpolation may prove disastrous in such cases. The interpolation accuracy could however be improved considerably by first transforming the age to a dimensionless number by normalizing it with the main-sequence lifetime of the star. The main-sequence lifetime is defined by the exhaustion of hydrogen in the stellar core. Since this lifetime was not readily available in the isochrone tables, we have empirically used an age that corresponds to the first increase in luminosity larger than $1\,{\rm mag}$ and occurring in less than 5% of the current age. After this transformation, we could compute adequate theoretical isochrones by linear interpolation in metallicity in all cases.

In a second step we determined the age corresponding to a pair of measured values, $T_{\rm eff}^0$ and M_v^0. This second interpolation is possible only when the measured values are properly bracketed by values of M_v and $T_{\rm eff}$ in the table. If there is an entry in the table for all 4 quadrants, defined by the signs of $T_{\rm eff} - T_{\rm eff}^0$ and $M_v - M_v^0$, the star is well bracketed and we can derive an age by interpolation. When we find points in 3 quadrants only, the star is near the limits of the tables ($10^{6.6}$ or $10^{10.3}$ years), but we may still derive an age by interpolation between these 3 values. If two or less points are available, an age cannot be derived from this table. We assign an age, written logarithmically as either $+\infty$ or $-\infty$, depending on which quadrants are empty.

The parameters $T_{\rm eff}^0$, M_v^0, and $[{\rm Fe/H}]^0$ are determined with some error. One can assign a probability distribution for the true value of these parameters and, hence, a probability distribution of ages. We assume a Gaussian distribution of the errors in $T_{\rm eff}$, M_v, and $[{\rm Fe/H}]$. The uncertainty in absolute visual magnitude M_v is not correlated with the uncertainty in metallicity and in effective temperature. The value of M_v is derived from independent measurements and its error is dominated by the uncertainty in the parallax. Metallicity and temperature errors may be correlated because $T_{\rm eff}$ and $[{\rm Fe/H}]$ are derived by fitting atmospheric models to observed spectra and colors. We have neglected the uncertainty in $[{\rm Fe/H}]$ because the error in $T_{\rm eff}$ turned out to be the most significant. If M_v^0 and $T_{\rm eff}^0$ are the measured values and ($T_{\rm eff}$,M_v) is a location in the HR-diagram, then the probability density is

$$\mathcal{P}(T_{\rm eff}, M_v) \;=\; \frac{1}{N}\exp\left\{-\frac{(M_v - M_v^0)^2}{2\Delta M_v}\right\} \times \exp\left\{-\frac{(T_{\rm eff} - T_{\rm eff}^0)^2}{2\Delta T_{\rm eff}}\right\} \qquad (1)$$

where N is a normalization factor and Δx is the uncertainty in x. The probability density of an age t is

$$\mathcal{P}(t) = \iint_{(T_{\rm eff}, M_v)} \delta\left(t(T_{\rm eff}, M_v) - t\right) \times \mathcal{P}(T_{\rm eff}, M_v)\,{\rm d}M_v{\rm d}T_{\rm eff} \qquad (2)$$

where $\delta(x)$ is the delta function. This probability distribution is not symmetric (see Fig. 1), and particularly so for young and/or cool stars. Since the isochrones cluster very tightly near the ZAMS, the error ellipse covers more isochrones of small ages than of large ages. This affects mostly the youngest stars that are close to the ZAMS, and late-type main-sequence stars whose initial evolution is almost parallel to the ZAMS. The probability density of the correct value of the age was obtained from a grid of points in the HR diagram, covering $\pm 3\sigma$ in $T_{\rm eff}$ and M_v with a step size of 0.2σ. By integration of this age probability density, we derived a median age and its one-sigma-like limits.

NB98 discussed carefully the uncertainties of the isochrone method related to stellar modeling. They compared ages derived from the Vandenberg (1985) and from the Bertelli et al. (1994) isochrones. The newer isochrones yield systematically larger ages for old stars ($t > 4Gyr$), but slightly lower ages for younger stars. They also discussed the improvement in age ac-

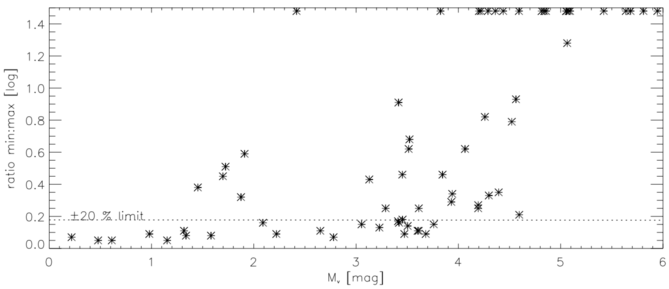

Fig. 2. Ratio of upper to lower age limit derived from isochrones as a function of the absolute magnitude M_v.

curacies brought by Hipparcos parallaxes. The remaining uncertainty in the age is dominated by the uncertainty in $T_{\rm eff}$.

2.1.1. Data and results

We derived absolute magnitudes, M_v, from V measurements in the Geneva catalogue (Rufener, 1989) and parallax data in the Hipparcos catalogue (ESA, 1997). The photometry (from the Geneva catalogue) is accurate to about 0.005 mag. Hipparcos parallaxes have an error of about 0.8 mas, for a typical star in our sample at 20 pc distance. This translates into an error of about 0.04 mag in the absolute magnitude. Therefore, we take 0.05 mag as the total error in M_v.

Effective temperature and metallicity are best determined from detailed spectral modeling. For the stars studied by Edvardsson et al. (1993), we used their values for $T_{\rm eff}$ and [Fe/H]. For the remaining stars, we used the Geneva photometric system with the calibration by Künzli et al. (1997, hereafter K97). The error in $T_{\rm eff}$ is estimated to about 1%. For stars hotter than 8100 K, the metallicity is not well constrained by the photometry and we used values given found in Berthet (1990). In few cases where the metallicity had not been determined, we assumed a solar metallicity.

Table A1 shows the ages derived with the isochrone method, and M_v, $T_{\rm eff}$ and [Fe/H] data. It is clear that the precision is better for either hot or old stars, since the luminosity evolution is more pronounced. This is illustrated in Fig. 2 where we have plotted the ratio of upper to lower age limit as a function of M_v. For stars with spectral types later than G5, the isochrone age determination becomes too unreliable to be used. In most cases the isochrone method provides us with a median age and a lower and upper limits. In 17 cases, however, we failed to derive a reliable lower limit; we used then a lower limit derived from one of the other dating methods.

Primarily, our work differs from previous studies in the treatment of errors. For example, NB98 take seven points ($T^0_{\rm eff}$, M^0_v, $[{\rm Fe/H}]^0$), ($T^0_{\rm eff}\pm\Delta T_{\rm eff}$,$M^0_v$, $[{\rm Fe/H}]^0$) ($T^0_{\rm eff}$, $M^0_v\pm\Delta M_v$, $[{\rm Fe/H}]^0$), and ($T^0_{\rm eff}$, M^0_v, $[{\rm Fe/H}]^0\pm\Delta[{\rm Fe/H}]$), compute the ages related to these points and consider these as independent and equiprobable measurements of the age (see Fig. 1). The age is then computed as the mean of these measurements and the scatter is used as the uncertainty. Because of the asymmetric nature of the probability distribution, NB98 underestimate the uncertainty towards low ages. Fig. 3 shows a comparison of the isochrone ages of stars in our sample and in the sample studied by NB98. While our median age always falls in the range given by NB98, we assign larger errors, especially towards lower ages.

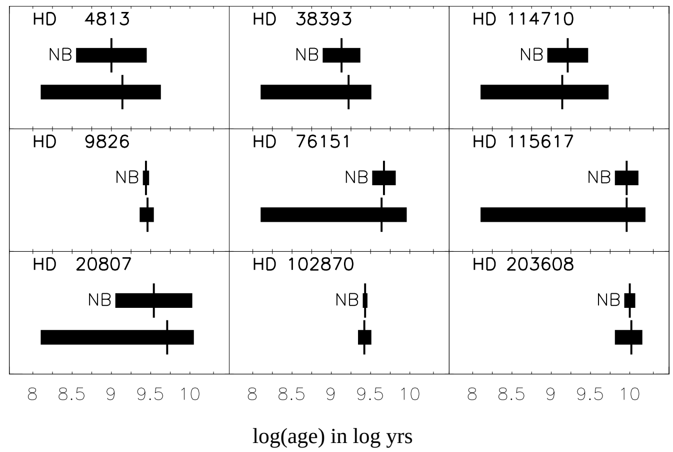

Fig. 3. Comparison of ages and uncertainties derived by NB98 and in this work. See text.

Vega and Sirius are two special cases in our sample because they exhibit abundance anomalies (e.g. Hill & Landstreet, 1993). Sirius shows metal overabundances while Vega shows underabundances. These anomalies are probably due to element diffusion in the photosphere or (in the case of Vega, see below) to accretion. Since stellar evolution is influenced mainly by the abundances in the stellar core we have assumed solar abundances for the computation of isochronic ages. For Sirius, neither solar abundances nor the measured metallicity of $[{\rm Fe/H}] = +0.12$ (Hill & Landstreet, 1993) leads to a meaningful age. The age of Vega is controversial. While most authors place it near 400 Myr (Backman & Paresce, 1993, e.g.), Holweger & Rentzsch-Holm (1995) have recently used Vega's peculiar abundances to conclude that Vega is a λ Bootis stars with ongoing accretion of dust–free gas. Since λ Bootis stars are still accreting, they may even be in the pre-main-sequence (PMS) stage.

Similarly, we have obtained an age of 275 Myr for β Pic (HD 39060). Due to the presence of a dense circumstellar disk, Lanz et al. (1995) argued that β Pic might be rather in the PMS phase and be as young as 10 to 15 Myr. We should point out here that the isochrone method yield bivalued results: very young ages if the star still contracts towards the ZAMS or older ages for stars evolving off the main-sequence. A simple lifetime argument suggests that most stars in our sample are evolving off the ZAMS. We have therefore made the systematic and most likely assumption that all stars in our sample are at least as old as stars on the ZAMS.

2.2. Rotation

Stars are born with relatively high rotational velocities. The rotation decreases with time due the loss of angular momentum with stellar winds. Stellar rotation can therefore be used in principle to estimate stellar ages, although an important uncertainty lies in the initial rotation rate of very young stars. However, since the angular momentum loss is a very steep function of the rotation period, all stars tend to reach a common value of the period within about 10^8 years after arrival on the main-sequence (Kawaler, 1989). Thus, the rotational period can be used as an age indicator only for stars older than this value.

The stellar rotation can be measured either directly from photometric variations (e.g. Strassmeier et al., 1997), or indirectly from the width of spectral lines which yields $v \sin i$. In main-sequence stars of spectral type G or later, rapid rotation is associated with strong chromospheric activity as measured by emission lines and X-ray emission. In this section, we discuss only rotation as an age indicator. The next section will cover activity as measured by calcium-line reversals.

We follow basically the work by Kawaler (1989) who found that a relation of the form

$$\log P = c \log t - d(c) \log \left(\frac{M_\star}{M_\odot} \right) + e(c) \quad (3)$$

is expected if the (weak) dependence of the deceleration on the mass loss rate is ignored. Here t is the age, P is the rotation period of the star, $M_\star$ its mass, and c, $d(c)$ and $e(c)$ are constants. We used $c = 0.375$ from Barry (1988) and $d(c) = 0.963$ from Kawaler (1989). $e(c)$ is determined by normalizing the relation to the Sun (see below).

To express the mass as a function of B-V, [Fe/H] and age, we used Bertelli et al.'s (1994) evolutionary tables. We derived the following relation

$$\log \frac{M}{M_\odot} = 0.269 - 0.368(\mathrm{B-V}) + 0.121[\mathrm{Fe/H}] \quad (4)$$

which is valid for $-0.4 \leq [\mathrm{Fe/H}] \leq 0.4$, $0.4 \leq \mathrm{B-V} \leq 1.2$, $8 \leq \log(t/1\,\mathrm{yr}) \leq 9.5$. For ages below 3 Gyr, this function turned out to be mostly age-independent. Ages above that limit may be slightly overestimated, but for late–type stars the relation still works reasonable well. Kawaler (1989) used different evolutionary models, and derived slightly different constants.

Combining these two relations, we obtain

$$\log \frac{t}{1\,\mathrm{yr}} = 2.667 \log \frac{P}{1\mathrm{day}} - 0.944(\mathrm{B-V}) - 0.309[\mathrm{Fe/H}] + 6.530 \quad (5)$$

where the constant term results from fitting the formula to the Sun.

2.2.1. Data and results

We used direct measurements of stellar rotation periods made at Mount Wilson, in particular Noyes et al. (1984) with an 1% accuracy and Baliunas et al. (1996) with 0.5 days or better accuracy. We decided to ignore projected velocities, $v \sin i$, because these would be useful only in a statistical sense. For individual stars, they may lead to large errors. For some stars, we used values by Saar & Osten (1997) derived from calcium emission.

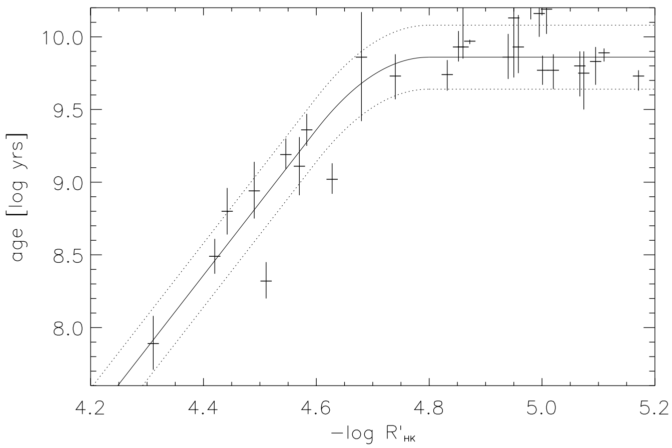

Fig. 4. Calibration of the calcium method for age determination for stars with $\mathrm{B-V} \geq 0.6$ and ages known from other methods. The solid line indicates the mean age. The dotted lines show the one–σ limits of the age distribution.

Metallicities are derived from the sources discussed in Sect. 2.1, with a average uncertainty of 0.08 dex. If the value is unknown, we assumed a solar metallicity; this introduces an error of less than 0.2 dex in logarithmic age (in years). In that case, we assumed a 0.30 dex uncertainty in metallicity. The colour in the Geneva photometry is measured with a precision of 0.004. We computed the error bars assuming a 0.10 dex internal error in $\log t$, as mentionned in Kawaler's 1989 paper.

The ages derived from rotation are listed in Table A2. The limited number of stars is mainly caused by the scarcity of measurements of rotational periods. Several stars have an age estimate in excess of 3 Gyr; in this case, Eq. (4) is less accurate and we have to reject these estimates, unless confirmed independently by other methods.

2.3. *Calcium emission lines*

For cool stars with convective outer-layers, chromospheric activity and rotation are linked by the stellar dynamo. Thus, like rotation, chromospheric activity declines with stellar age.

A common and easily observed indicator of chromospheric activity is the ratio R'_{HK} (Noyes et al., 1984) which measures the emission in the calcium H and K bands relative to the total stellar flux. We could have followed previous studies linking R'_{HK} to the rotation period, and then determine the stellar age with the relation derived in Sect. 2.2. Alternatively, we may derive a direct relation between the age and R'_{HK}. We prefer the second method.

To calibrate this method, we used for each star in our sample the "best" age chosen as described in Sect. 3 from isochrone, rotation or metallicity ages. We plotted these ages against R'_{HK} values taken from the studies by Baliunas et al. (1996), Henry et al. (1996) and Noyes et al. (1984). The scatter in the R'_{HK}–age relation is mainly due to stars with $\mathrm{B-V} < 0.6$. Therefore, we restrict ourselves to redder stars, i.e. $\mathrm{B-V} \geq$

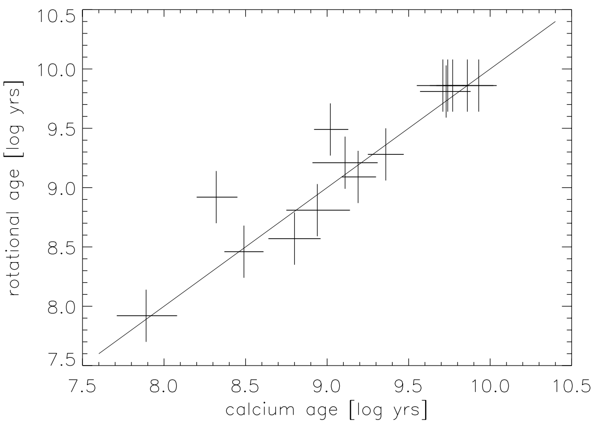

Fig. 5. Comparison between the ages derived from rotation and from calcium emission.

0.6. Fig. 4 displays our relation which can be fitted by the following formula

$$\log t_{\rm yrs} = \begin{cases} \alpha+\beta x & \text{if } x<0 \\ \alpha+\beta x+\gamma x^2 & \text{if } 0\le x<0.2 \\ \alpha+0.2\beta+0.04\gamma & \text{if } x\ge 0.2 \end{cases} \quad (6)$$

$$x = -\log R'_{\rm HK} - 4.6 \quad \alpha = 9.36 \quad \beta = 5.0$$
$$\gamma = -12.5$$

For the upper and lower one-σ-like limits, we computed the standard deviation from the fit, assuming that it is independent of $R'_{\rm HK}$ and find $\sigma = 0.22$ in $\log(t/1{\rm yr})$. The ages derived from calcium emission lines are listed in Table A3. They are mean ages, but very close to the median value because the distribution is quite symmetrical.

We had mentioned above, that calcium and rotation ages should be in good agreement since the methods both measure either directly or indirectly the stellar rotation. Fig. 5 compares the results of both methods. Within the errors, the methods agree well. Note that the ages are not entirely independent since some rotational ages have been used in the calibration of the calcium method.

2.4. Kinematics

Stars are born in molecular clouds with a low velocity with respect to the local standard of rest (LSR) (Wielen, 1977). They perform a random walk in velocity space mostly due to scattering by molecular clouds. Statistically, their kinetic energy increases with time. Since the masses of the scattering bodies are much larger than the stellar masses, the increase in space velocity dispersion is independent of stellar mass. Thus, the space velocity of a star (rather than its energy) is an age indicator, but the associated probability distribution is quite broad. Due to the nature of the random walk process, this allows only to determine a lower limit to the age.

Assuming a random change of velocity at each encounter that is independent of time, one obtains a Brownian-like dispersion of the stellar velocity: $\Delta v^2 = (\Delta v)_0^2 + At = B^2 + At$, where $(\Delta v)_0 = B$ represents the initial scatter ($t = 0$) in velocity of a group of stars, and Δv the scatter at time t (Wielen, 1977). A and B are constants.

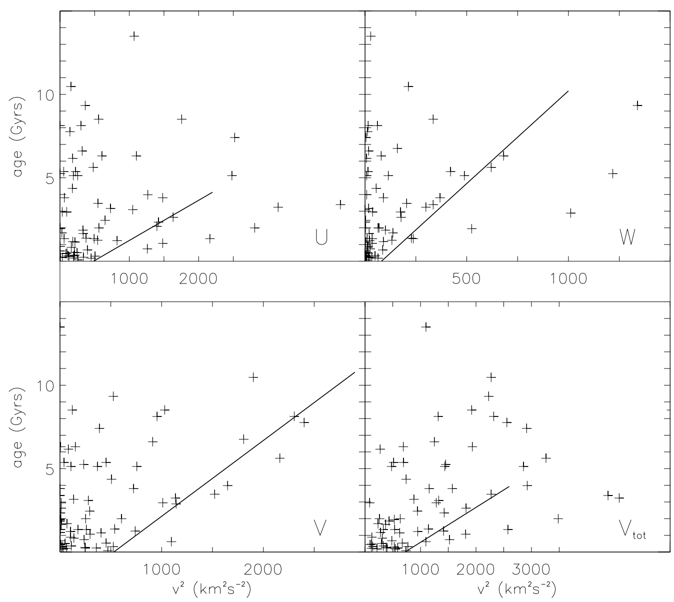

Fig. 6. Plot of spatial motion energy and known stellar ages. The four diagrams show this relation for the components along the galactic coordinate U, V, and W, and for the total energy.

At time t, most stars have velocities lower or of the order of Δv. Replacing for an individual star the statistical parameter Δv by $\|\boldsymbol{v}\|$, we can define a lower limit to the stellar age

$$t_{\rm min} = \max\left\{0, \frac{\|\boldsymbol{v}\|^2 - B^2}{A}\right\} \quad . \quad (7)$$

Similarly to this relation for the total spatial motion of the star, we can write relations for each individual components along the galactic coordinates U, V, and W.

2.4.1. Data and results

The three components (U, V, W) of the stellar velocity with respect to the local standard of rest are computed from the radial velocity and the proper motion. The proper motions are taken from the ACT catalogue (Urban et al., 1998) if available, and otherwise from the Hipparcos Catalogue (ESA, 1997); the radial velocities are from Duflot et al. (1995). We have corrected for the solar motion using (-13.4 $\rm km/s$, -11.1 $\rm km/s$, 6.9 $\rm km/s$) from Chen et al. (1997), but we have ignored a correction for galactic rotation because the stars are all within 25 pc. We have calibrated the relation (7) using the stars in our sample which have good isochrone or rotational ages. Fig. 6 displays the velocity square versus age relation. For each component, we have fitted a linear relation which can be considered as a lower limit to the age in the sense that 67% of stars are older than this limit. The fit coefficients are given in Table 1. Ages are expressed in this case in Gyr and velocities in km/s. We did not derive an independent fit for the total space velocity, but added the coefficients of the individual components quadratically. This fits the data quite well.

Table 1. Fit coefficients for spatial motion–age relation

component	A $[km^2/s^2Gyr]$	B $[km/s]$	$(v_i^2)_{\max}$ $[km^2/s^2]$
U	415	22	2150
V	220	23	2900
W	90	9	1000
total	478	33	2500

Table 2. Fit for metallicity age limits. Minimum ages for low metallicity stars are given in the left column, and maximum ages for metal–rich stars are given in the right column.

[Fe/H]	$\log t_{\min}$ [yrs]	[Fe/H]	$\log t_{\max}$
$>$ -0.21	$-\infty$	$<$ -0.20	$+\infty$
-0.21	8.5	$=$ -0.20	9.92
-0.22	9.0	0.00	9.81
-0.30	9.1	0.10	9.63
-0.40	9.4	0.15	9.30
-0.50	9.6	0.23	9.00
-0.60	9.72	$\geq$ 0.24	9.00
-0.70	9.78		
$<$ -0.80	9.80		

The value of 478 $km^2\,s^{-2}\,Gyr^{-1}$ can be compared with the value of 600 $km^2\,s^{-2}\,Gyr^{-1}$ found by Wielen (1977) in his classical paper. Kinetic energies above a certain limit would indicate unrealisticly large ages. Therefore, we limited the fit somewhat arbitrarily to a point where the calibration plot indicates that the scatter becomes very large (Fig. 6). We list the adopted limit $(v_i^2)_{\max}$ in Table 1. We use the tightest limit derived from any of the three components or the total motion to define the lower limit to the stellar ages. The derived limits are listed in Table A4.

2.5. *Iron abundance*

The fraction of interstellar atoms more massive than helium increases with time, and may therefore be used as an indicator of stellar age. This is also a relatively inaccurate age indicator, with considerable uncertainties due to galactic chemical gradients, internal gradients in clusters (Carraro et al., 1998) and local inhomogeneities. Photospheric chemical anomalies may also be misleading. Therefore, the spread in an age-metallicity relation is large, especially for ages smaller than 10 Gyr. Metallicity is thus best suited to provide a lower limit to a stellar age: stars in our Galaxy with very low metallicities are old.

We used the age-metallicity relation derived by Carraro et al. (1998) from the study of open clusters and of the solar neighborhood. From their Fig. 8, we derived the following estimate (Table 2) for the upper and lower one-sigma limits of the distribution (i.e. 2/3 of the stars at a given age are between these two limits):

The age limits derived from this method are listed in Table A5.

3. Putting it all together

Since most methods have only a limited applicability, we almost always need to consider simultaneously different methods to derive the age of main-sequence stars. For example, the isochrone estimator works best for massive stars, the chromospheric activity indicator works best for late-type stars, while other methods often give only an upper or a lower limit to the age. Ideally, the different estimators should provide consistent ages for any given star. In our study, this is not always the case. The adoption of final values require therefore careful attention. We have defined the following criteria.

1. For stars with spectral types in the range B9–G5, isochrones clearly provide the best results, with the smallest errors. If the minimum and maximum age estimated in this way differ by no more than 0.4 dex in $\log t$[yr], we adopted this value as the best estimate.
2. For stars redder than B-V=0.6 (corresponding to spectral type G1-2V), both rotation and the calcium method provide an age estimate with a typical uncertainty of 0.4 to 0.5 dex in $\log t$[yr], which is adequate for our purposes. When both indicators were available, we averaged the two ages if the difference between the two estimates was less than 0.08 dex. Otherwise, we adopted the rotational age.
3. If neither 1 nor 2 could be used (no available data or the star does not fulfill the applicability criteria), we used a combination of different methods. First, we dismissed the results of the less reliable methods when they were clearly inconsistent with the other results. Then, we defined the age range to be the intersection of all remaining age intervals. In practice, this often means that one method defines the upper limit, and another method the lower limit. The adopted stellar age is either the median of this age interval, or the isochrone age if it falls within this range.
4. If the lower limit of an age was undetermined, we set its logarithmic value to zero (i.e. one year). If the upper limit was undetermined, we set it to 10.1. This upper limit of 12.6 Gyr is close to the age of the Galaxy and should provide a reasonable upper age limit for stars in the solar neighborhood. We also used these limits if the methods discussed under items 1–3 would formally indicate a negative age or an age above 10.1. When the median age derived for a star depends upon one of these arbitrarily fixed limits, we have enclosed the derived age in Table A6 in parenthesis, to indicate that these ages are less reliable. This was the case for 7 stars in the sample.

Fig. 7 shows the age ranges derived with different methods for a random[1] group of 10 stars in our sample. This illustrates how the different methods work together. Frequently, when several methods could be applied, they agree fairly well (e.g HD 115617). Some stellar ages are completely determined by isochrones (HD 106591, 117176, 120136, 126660). The figure shows also several examples where the two limits are derived

[1] random in the sense of physical properties. The group is one block of stars when the sample is sorted by right ascension.

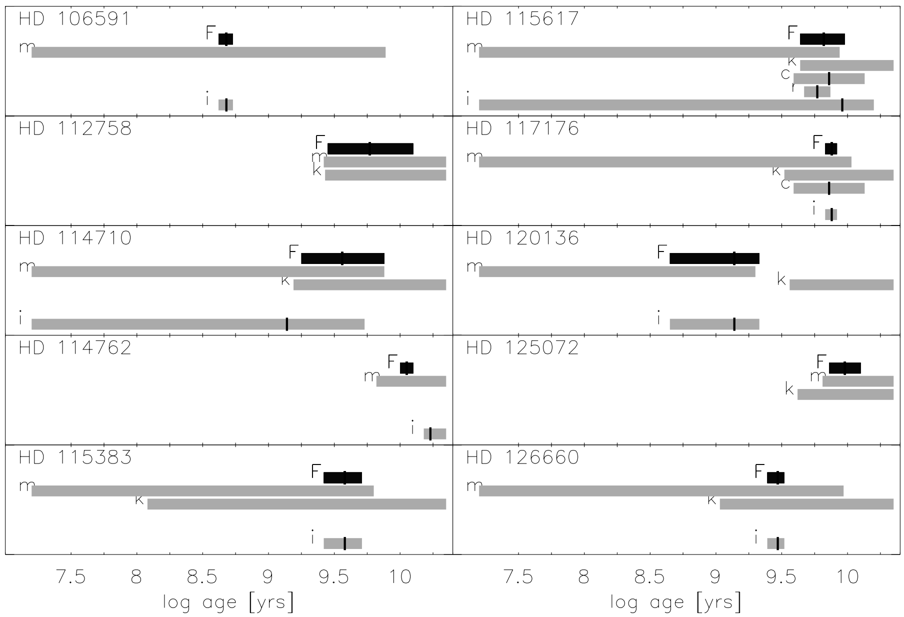

Fig. 7. Comparison of the age ranges derived with the different methods for 10 stars of our sample. This plot illustrates how the final ages are selected. The letters indicate the methods used: **i**sochrones,**r**otation, **c**alcium lines, **k**inematics, **m**etallicity, **F**inal ages.

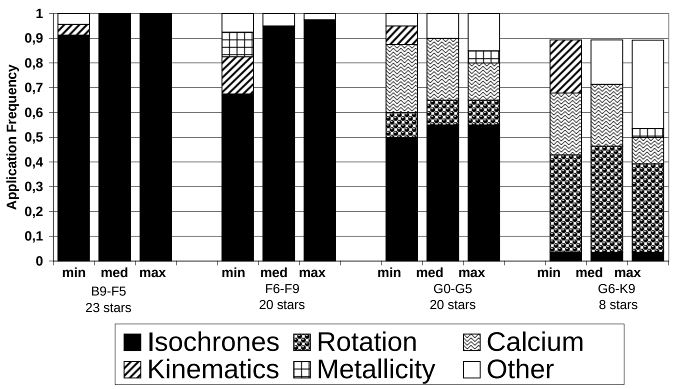

Fig. 8. Method used for the age determination. For each group of spectral types we plot the method used to determine the minimum age, the median (most probable) age and the maximum age. Some columns do not not reach a total of 1 because the necessary stellar data was unavailable or the age determination failed. The "Limit" method refers to an age limit given by zero or the age of our Galaxy.

from different methods: HD 115617 from rotation and kinematics, HD 112758 from kinematics and the age of the Galaxy, and HD 114710 from kinematics and metallicity. HD 114762 is one of the few problematic cases. The isochronic age derived was 19 Gyr, which is unrealistic. An upper limit is given by criterion 4, while the lower limit is set from the lower limits derived from metallicity and isochrones.

The final ages, the upper and lower one-σ–like limits and the method used for the determination of each of the 3 values are collected in Table A6 for 91 stars. The following stars require a few additional remarks:

– HD 38392 and HD 38393. According to the Hipparcos catalogue (ESA, 1997) a physical double star. The age range we derived for HD 38392 is included in that of HD 38393, but the median age of HD 38393 does not fall into the range derived for HD 38392. Assuming that the stars formed at the same time, we can deduce an age range of 562 Myr to 1.38 Gyr.
– Sirius (HD 48915): As mentioned in Sect. 2.1.1, the isochrone method did not provide any reasonable result for Sirius with either measured or solar metallicity.
– β Pic (HD 39060) and Vega (HD 172167): From isochrones we find median ages of 275 and 350 Myr, respectively. For both of these stars, much younger ages have also been proposed. See discussion Sect. 2.1.1.
– 51 Peg (HD 217014), 70 Vir (HD 117176), 47 UMa (HD 95128), HD 114762. These stars have been studied in detail because of the recent detection of orbiting planets. Stellar properties have been discussed by Henry et al. (1997) who find ages consistent with ours for 47 UMa, 70 Vir and HD 114762. However, they derive a higher age for 51 Peg. According to our criterion 1 we have used the isochronic age which gives the narrowest range. The isochronic age quoted by Henry et al. (1997, taken from Edvardsson et al. 1993) is slightly higher than the upper limit of our range (8.5 Gyr versus 4.4–8.1 Gyr) which is probably due to the different set of isochrones used by Edvardsson et al.. The rotation and calcium ages we derived are consistent with the numbers given by Henry et al. (1997).

As can be seen in Table A6, the isochrone method has the highest hit rate (about 55% of the estimates); 25% of the estimates are based on rotation and/or chromospheric activity; the remainder, almost all estimates of an upper or a lower limit, are based on space velocities or stellar metallicities.

Fig. 8 splits this information into four different spectral class bins: B9-F5, F6-F9, G0-G5, and G6-K9. These bins are chosen in order to contain about an equal number of stars, except the last one; the isochrone method ceases to be useful at spectral types later than G5. This last bin contains fewer stars than the others.

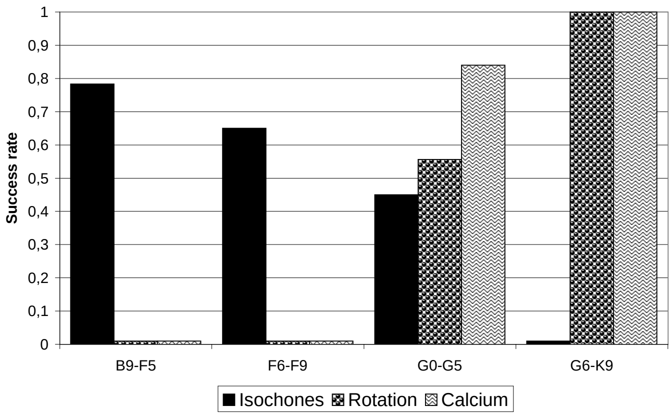

Fig. 9. Fraction of success for three age determination methods. Success is defined by requiring a maximum ratio between upper and lower limit of $10^{0.5}$. The success rate is the number of stars where this accuracy was reached with a the method divided by the number of stars where we had the required data available.

For the hottest stars in our sample (spectral range B9-F5), the isochrone method worked well throughout. Only for a few stars that are too close to the ZAMS, we needed to adopt a lower limit from a different method. In the next spectral bin (F6-F9), isochrones are still most useful to determine the median stellar age and an upper limit, but the lower limit cannot be defined properly in 30% of the cases. Since late F-type stars are still too hot and too young for the rotation and calcium methods to work well, lower limits for these stars are best derived from kinematics and metallicity. In the third group (the early G-type stars, G0-G5), isochrones still work for about half of the stars. For the remaining cases, stellar rotation and calcium emission provide good ages. Finally, rotation and calcium emission are the main age indicator for the cool late-type main-sequence stars. However, there remains a significant fraction of stars (17%) for which we cannot define a median age, and even 42% for which we cannot determine an upper limit other than the age of the Galaxy.

Even when the required data are available, the stellar age may remain poorly determined. To illustrate this point, we define a determination as *successful* if the ratio between the upper and lower age limit is less than 0.5 dex. Success rates are displayed in Fig. 9. For cool stars, rotation and calcium lines are successful in all cases when the necessary data are available. For the early G-type stars, the calcium method is still successful in more than 80% of the cases, rotation in about 50% and isochrones in about 45%. For the hotter stars, only isochrones are efficient. However, even for the hottest group, the success rate does not exceed 80%.

4. Conclusions

We have used a variety of methods to determine the ages of a sample of nearby, field main-sequence stars. No single method can be used for all stars. In many cases, a combination of several methods is required to properly bracket stellar ages. With this combination method we were able to determine age estimates for 86 out of 91 stars. The most successful dating methods are isochrones for hot stars and stellar rotation and activity for cool stars. However, also metallicity and stellar kinematics provide valuable constrains.

The mean logarithmic uncertainties of the successful age determinations are $+0.16$ and -0.19 if we exclude the 3 stars where no lower limit could be determined. We have also shown that neglecting the asymmetric distribution of isochrones in the HRD can lead to smaller error estimates. The derived ages compare well with previous determinations. A higher accuracy may be achievable with detailed studies of individual stars including accurate atmospheric modeling. However, the age estimates discussed in this paper are based on readily available data. The methods can be applied to samples of stars where individual studies are not available.

Acknowledgements. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France, of the GCPD General Catalogue of Photometric Data (GCPD) operated at the University of Lausanne, Switzerland, and the ACT Reference catalogue. CD acknowledges support from the Stichting Astronomisch Onderzoek (ASTRON, project nr. 781-76-015).

Appendix A: ages as determined from different methods

Table A1. Ages from Bertelli's isochrones

star	observational data			isochronic ages			Ref	star	observational data			isochronic ages			Ref
HD	$T_{\rm eff}$	[Fe/H]	M_v	low	med	upper		HD	$T_{\rm eff}$	[Fe/H]	M_v	low	med	upper	
	[K]		[mag]		[log yrs]				[K]		[mag]		[log yrs]		
693	6206	-0.36	3.504	9.63	9.71	9.77	K	101501	5554	-0.20	5.421	$-\infty$	9.60	10.20	K
1581	5991	-0.28	4.563	9.10	9.81	10.03	K	102365	5692	-0.38	5.064	9.72	10.14	$+\infty$	K
4813	6254	-0.15	4.219	$-\infty$	9.14	9.63	E	102647	8582	-0.02	1.910	7.99	8.38	8.58	KB
7570	6078	0.10	4.065	9.03	9.50	9.65	E	102870	6176	0.13	3.410	9.34	9.42	9.51	E
9826	6212	0.05	3.454	9.36	9.46	9.54	E	106591	8630	0.02	1.318	8.62	8.68	8.73	KB
10700	5483	-0.56	5.683	$-\infty$	10.17	$+\infty$	K	112758	5408	-0.20	5.945	!	!	!	K
10780	5417	-0.16	5.637	$-\infty$	9.47	$+\infty$	K	114710	6029	0.03	4.438	$-\infty$	9.14	9.73	E
12311	7077	0.11	1.153	8.89	8.91	8.94	K	114762	5871	-0.74	4.259	10.18	10.23	$+\infty$	E
13709	9615	0.00	0.219	8.50	8.53	8.57	KA	115383	6021	0.10	3.931	9.42	9.58	9.71	E
14412	5421	-0.89	5.809	![1]	!	!	K	115617	5590	-0.03	5.079	$-\infty$	9.96	10.20	E
14802	5848	-0.16	3.472	9.70	9.73	9.79	K	117176	5596	-0.15	3.681	9.83	9.88	9.92	K
15008	8918	0.00	0.979	8.61	8.65	8.70	KA	120136	6398	0.20	3.522	8.65	9.14	9.33	K
17051	6081	0.04	4.201	$-\infty$	9.49	9.71	K	126660	6280	-0.07	3.228	9.39	9.47	9.52	K
19373	6040	0.14	3.940	9.32	9.53	9.66	K	128167	6767	-0.41	3.514	8.86	9.30	9.48	E
20630	5747	-0.03	5.053	$-\infty$	$+\infty$	$+\infty$	K	134083	6500	-0.00	3.452	8.94	9.26	9.40	E
20766	5751	-0.31	5.092	$-\infty$	9.87	10.17	K	135379	8686	0.08	1.698	8.10	8.39	8.55	KB
20807	5889	-0.23	4.814	$-\infty$	9.71	10.05	E	139664	6676	-0.05	3.415	8.39	9.05	9.30	K
22001	6621	-0.11	3.054	9.23	9.31	9.38	E	142373	5843	-0.52	3.612	9.85	9.93	9.96	E
22484	5981	-0.11	3.602	9.66	9.72	9.77	E	142860	6333	-0.16	3.613	9.38	9.51	9.63	E
30495	5824	-0.13	4.857	$-\infty$	9.67	10.03	K	157214	5791	-0.41	4.595	10.04	10.19	10.25	E
33262	6164	-0.24	4.361	$-\infty$	9.47	9.81	K	157792	7267	0.28	2.089	8.78	8.87	8.94	K
34411	5889	-0.03	4.194	9.66	9.83	9.93	E	160691	5746	0.19	4.194	9.63	9.79	9.88	K
38393	6398	-0.07	3.825	$-\infty$	9.22	9.51	E	172167	9616	0.0	0.612	8.50	8.54	8.59	KA
38678	8546	-0.07	1.875	8.37	8.57	8.69	KB	173667	6369	-0.11	2.780	9.33	9.38	9.40	E
39060	8035	-0.15	2.418	$-\infty$	8.44	8.72	K	185395	6747	0.03	3.129	8.81	9.11	9.24	K
43834	5626	0.01	5.057	$-\infty$	9.83	10.16	K	187642	7548	-0.34	2.221	9.04	9.09	9.13	K
48915	9915	0.0	1.453	![1]	!	!	KA	197692	6543	-0.04	3.289	9.14	9.30	9.39	K
61421	6704	-0.02	2.650	9.17	9.23	9.28	E	203280	7567	-0.03	1.582	8.91	8.95	8.99	K
69897	6365	-0.26	3.845	9.21	9.54	9.67	E	203608	6146	-0.69	4.394	9.81	10.02	10.16	K
76151	5763	0.04	4.840	$-\infty$	9.64	9.96	E	207129	5933	-0.08	4.592	$-\infty$	9.64	9.92	K
84737	5899	0.04	3.759	9.63	9.73	9.78	E	215789	8415	-0.20	0.478	8.71	8.73	8.76	KB
90839	6191	-0.10	4.289	$-\infty$	9.07	9.66	K	216956	8681	0.08	1.724	8.02	8.35	8.53	KB
95128	5882	0.01	4.298	9.59	9.80	9.92	E	217014	5812	0.14	4.522	9.12	9.71	9.91	K
97603	8199	-0.07	1.337	8.79	8.83	8.87	KB	222368	6192	-0.16	3.420	9.51	9.58	9.67	K

References: **K**: Geneva Photometry with calibration from Künzli et al. 1997; **E**: Edvardsson et al. 1993; **A**: solar value assumed; **B**: Berthet et al. 1990; [1] badly placed on HR diagram: no computation possible.

Table A2. Rotational ages

star	data			rotational ages			sources	
HD	P	B-V	[Fe/H]	lower	mean	upper	[Fe/H]	P
	[days]	[mag]	[log]		[log yrs]			
4628	38.0	0.88	-0.06	9.83	9.93	10.04	Z	B
10780	23.0	0.81	-0.16	9.34	9.45	9.55	K	N
13445	30.0	0.82	-0.11	9.57	9.73	9.88	Z	S

Table A2. (continued)

star	data			rotational ages			sources	
HD	P [days]	B-V [mag]	[Fe/H] [log]	lower	mean [log yrs]	upper	[Fe/H]	P
17925	6.6	0.87	0.00	7.71	7.89	8.08	A	B
20630	9.4	0.68	-0.03	8.37	8.49	8.61	K	B
30495	7.6	0.63	-0.13	8.20	8.32	8.45	K	B
37394	11.0	0.84	-0.05	8.43	8.53	8.63	Z	N
38392	17.3	0.94	0.00	8.75	8.94	9.14	A	S
43384	32.0	0.72	0.01	9.71	9.86	10.02	K	S
76151	15.0	0.67	0.04	8.92	9.02	9.13	E	N
101501	17.0	0.72	-0.20	9.09	9.19	9.30	K	N
102365	24.0	0.66	-0.38	9.55	9.71	9.86	K	S
115617	29.0	0.71	-0.03	9.67	9.77	9.87	E	N
149661	21.3	0.82	-0.20	9.25	9.36	9.47	Z	B
156026	18.0	1.14	0.00	8.64	8.80	8.96	A	B
166620	42.0	0.87	-0.40	10.00	10.16[1]	10.32	A	B
185144	27.0	0.79	-0.44	9.63	9.74	9.84	K	N
191408	45.0	0.87	-0.51	10.12	10.28[1]	10.43	Z	S
209100	22.0	1.06	0.00	8.91	9.11	9.31	A	S

References and Notes: **Z**: Zakhozhaj & Shaparenko 1996; **N**: Noyes et al. 1984; **K**: Geneva photometry with calibration from Künzli's et al. 1997; **B**: Baliunas, Sokoloff and Soon 1996; **S**: Saar & Osten 1997; **E**: Edvardsson et al.1993; **A**: Metallicity assumed, taken to be consistent with the age found; [1]Age overestimated.

Table A3. Calcium ages

star HD	CaII emission $\log R'_{\rm HK}$	Ref	age log yrs	star HD	CaII emission $\log R'_{\rm HK}$	Ref	age log yrs	star HD	CaII emission $\log R'_{\rm HK}$	Ref	age log yrs
4628	-4.852	B	9.86	38392	-4.490	H	8.81	154088	-5.000	H	9.86
10700	-4.958	B	9.86	43834	-4.940	H	9.86	156026	-4.442	B	8.57
13445	-4.740	H	9.81	74576	-4.310	H	7.91	157214	-5.008	N	9.86
14412	-4.860	H	9.86	76151	-4.628	N	9.49	160691	-5.020	H	9.86
17925	-4.311	B	7.92	84737	-5.171	N	9.86	166620	-4.995	B	9.86
19373	-5.102	N	9.86	95128	-5.067	N	9.86	185144	-4.832	B	9.86
20630	-4.420	N	8.46	100623	-4.860	H	9.86	191408	-4.980	H	9.86
20766	-4.680	H	9.68	101501	-4.546	B	9.09	207129	-4.800	H	9.86
20807	-4.787	N	9.86	102365	-4.950	H	9.86	209100	-4.570	H	9.21
26965	-4.872	B	9.86	115617	-5.001	B	9.86	217014	-5.074	B	9.86
30495	-4.511	B	8.92	117176	-5.110	N	9.86				
34411	-5.095	N	9.86	149661	-4.583	B	9.28				

References: **B**: Baliunas, Sokoloff & Soon 1996; **H**: Henry et al. 1996; **N**: Noyes et al. 1984.

Table A4. Kinetic ages

star HD	observational data U [km/s]	V [km/s]	W [km/s]	age min	Ref	star HD	observational data U [km/s]	V [km/s]	W [km/s]	age min	Ref
693	9.2	-1.6	-11.2	>8.71	W	20807	-24.3	-8.0	2.8	>8.43	U
1581	11.2	26.7	-30.9	>9.99	W	22001	-30.5	-13.4	8.4	>9.04	U
4628	-31.0	-37.4	-4.0	>9.60	V	22484	0.0	-4.0	-34.8	>8.47	E
9826	67.2	32.9	-20.6	>9.59	W	26965	42.2	34.1	36.7	>9.49	U
10700	54.0	44.7	18.2	>9.82	V	34411	-49.4	-24.4	12.3	>8.89	W
13445	-4.6	3.8	-49.4	>9.46	E	38393	24.4	15.0	-4.3	>8.43	U
14412	34.0	38.5	-1.7	>9.64	V	50281	27.8	25.8	-12.6	>9.02	E
19373	-12.9	10.4	18.4	>9.46	W	61421	7.9	2.8	-11.6	>8.79	W
20766	-24.9	-8.5	2.3	>8.53	U	69897	-31.7	-27.8	14.4	>9.28	E

Table A4. (continued)

star	observational data			age		star	observational data			age	
HD	U	V	W	min	Ref	HD	U	V	W	min	Ref
	[km/s]						[km/s]				
84737	10.7	4.8	20.5	>9.58	W	134083	19.7	9.9	-9.8	>8.28	W
88230	-4.1	-7.9	-22.4	>9.67	W	142860	5.4	-22.5	-17.1	>9.38	W
90839	6.2	9.4	9.6	>8.09	W	149661	12.0	10.1	-22.8	>9.69	W
97603	20.8	10.3	-9.2	>7.79	W	154088	6.5	-3.8	-10.0	>8.37	W
100623	12.5	31.5	18.3	>9.45	W	157881	-34.9	-42.0	-2.7	>9.75	V
102365	27.3	11.8	-5.1	>8.80	U	173667	30.7	13.2	-0.9	>9.04	U
102870	33.0	14.5	13.3	>9.16	U	185144	65.0	51.7	-2.7	>9.99	V
112758	-46.6	-19.6	18.3	>9.45	W	185395	-20.8	-16.0	11.5	>8.76	W
114710	6.6	24.4	15.5	>9.25	W	191408	-82.7	-42.3	57.5	>9.76	V
115383	-1.3	11.9	-9.3	>7.91	W	192310	-26.3	-1.5	-6.1	>8.71	U
115617	-37.9	-35.3	-24.7	>9.77	W	203608	48.2	54.8	14.7	>9.18	W
117176	-26.3	-37.8	3.5	>9.62	V	209100	-44.3	-27.0	27.3	>9.87	W
120136	42.5	34.3	-15.0	>9.50	U	217014	-17.2	-16.3	22.2	>9.66	W
125072	-18.5	-6.9	-26.9	>9.86	W	219134	-24.2	-18.0	3.6	>8.41	U
126660	-11.4	-20.5	13.2	>9.02	W	222368	-14.3	-15.6	-19.0	>9.50	W
128167	28.8	27.1	1.6	>8.99	E						

Notes: **U,V,W**: from the corresponding space velocity component; **E**: from the total velocity.

Table A5. Metallicity datation

HD	[Fe/H]		age	HD	[Fe/H]		age	HD	[Fe/H]		age
693	-0.36	K	>9.52	38678	-0.07	K	<9.97	125072	-0.70	F	>9.81
1581	-0.28	K	>9.27	39060	-0.15	K	<10.03	126660	-0.07	K	<9.97
4628	-0.06	F	<9.96	43834	0.01	K	<9.90	128167	-0.41	E	>9.61
4813	-0.15	E	<10.03	48915	0.00	A	?	134083	-0.00	E	<9.92
7570	0.10	E	<9.80	50281	0.07	F	<9.82	135379	0.08	K	<9.83
9826	0.05	E	<9.86	61421	-0.02	E	<9.93	139664	-0.05	K	<9.96
10700	-0.56	K	>9.75	69897	-0.26	E	>9.15	142373	-0.52	E	>9.73
10780	-0.16	K	<10.04	74576	-0.19	F	<10.07	142860	-0.16	E	<10.04
12311	0.11	K	<9.77	76151	0.04	E	<9.87	149661	-0.20	F	<10.08
13445	-0.11	F	<10.00	81997	0.00	K	<9.92	156026	-0.18	F	<10.06
13709	0.00	K	<9.92	84737	0.04	E	<9.87	157214	-0.41	E	>9.61
14412	-0.89	K	>9.85	90839	-0.10	K	<10.00	157792	0.28	K	<9.00
14802	-0.16	K	<10.04	95128	0.01	E	<9.90	160691	0.19	K	<9.36
15008	0.00	K	<9.92	97603	-0.07	K	<9.97	172167	0.00	A	?
17051	0.04	K	<9.87	100623	-0.27	F	>9.21	173667	-0.11	E	<10.00
19373	0.14	K	<9.66	101501	-0.20	K	<10.08	185144	-0.44	K	>9.64
20630	-0.03	K	<9.94	102365	-0.38	K	>9.56	185395	0.03	K	<9.88
20766	-0.31	K	>9.42	102647	-0.02	K	<9.93	187642	-0.34	K	>9.48
20807	-0.23	E	>9.03	102870	0.13	E	<9.70	191408	-0.51	F	>9.72
22001	-0.11	E	<10.00	106591	0.02	K	<9.89	197692	-0.04	K	<9.95
22484	-0.11	E	<10.00	112758	-0.31	K	>9.42	203280	-0.03	K	<9.94
26965	-0.08	F	<9.98	114710	0.03	E	<9.88	203608	-0.69	K	>9.80
30495	-0.13	K	<10.02	114762	-0.74	E	>9.82	207129	-0.08	K	<9.98
33262	-0.24	K	>9.06	115383	0.10	E	<9.80	215789	-0.20	K	<10.08
34411	-0.03	E	<9.94	115617	-0.03	E	<9.94	216956	0.08	K	<9.83
37394	-0.05	F	<9.96	117176	-0.15	K	<10.03	217014	0.14	K	<9.66
38393	-0.07	E	<9.97	120136	0.20	K	<9.30	222368	-0.16	K	<10.04

References: **K**: Künzli et al. 1997; **E**: Edvardsson et al. 1993; **F**: Fatava et al. 1997; **A**: Assumed solar, no age derived.

Table A6. Final ages

star	Values for the age			Method used			star	Values for the age			Method used		
HD	min	median	max	min	median	max	HD	min	median	max	min	median	max
693	9.63	9.71	9.77	I	I	I	101501	9.09	9.19	9.39	R&C	R&C	R&C
1581	9.53	9.81	10.03	M&K	I	I	102365	9.72	9.86	10.08	I	C	C
4628	9.74	9.90	10.04	R&C	R&C	R	102647	7.99	8.38	8.58	I	I	I
4813	0	9.14	9.63	A	I	I	102870	9.34	9.42	9.51	I	I	I
7570	9.03	9.50	9.65	I	I	I	106591	8.62	8.68	8.73	I	I	I
9826	9.36	9.46	9.54	I	I	I	112758	9.45	(9.77)	10.10	K	A	A
10700	9.64	9.86	10.08	C	C	C	114710	9.25	(9.56)	9.88	K	A	M
10780	9.34	9.45	9.55	R	R	R	114762	10.00	(10.05)	10.10	I&A	A	I&A
12311	8.89	8.91	8.94	I	I	I	115383	9.42	9.58	9.71	I	I	I
13445	9.57	9.73	9.88	R	R	R	115617	9.64	9.82	9.98	K	R&C	R&C
13709	8.50	8.53	8.57	I	I	I	117176	9.83	9.88	9.92	I	I	I
14412	9.64	9.86	10.08	C	C	A	120136	8.65	9.14	9.33	I	I	I
14802	9.70	9.73	9.79	I	I	I	125072	9.86	(9.98)	10.10	K	A	A
15008	8.61	8.65	8.70	I	I	I	126660	9.39	9.47	9.52	I	I	I
17051	0	9.49	9.71	A	I	I	128167	8.99	9.23	9.48	K	I	I
17925	7.61	7.91	8.11	R&C	R&C	R&C	134083	8.94	9.26	9.40	I	I	I
19373	9.32	9.53	9.66	I	I	I	135379	8.10	8.39	8.55	I	I	I
20630	8.31	8.48	8.65	R&C	R&C	R&C	139664	8.39	9.05	9.30	I	I	I
20766	9.46	9.68	9.90	C	C	C	142373	9.85	9.93	9.96	I	I	I
20807	9.64	9.86	10.08	C	C	C	142860	9.38	9.51	9.63	I	I	I
22001	9.23	9.31	9.38	I	I	I	149661	9.16	9.32	9.49	R&C	R&C	R&C
22484	9.66	9.72	9.77	I	I	I	154088	9.64	9.86	10.08	C	C	C
26965	9.64	9.86	10.08	C	C	C	156026	8.64	8.80	8.96	R	R	R
30495	8.20	8.32	8.45	R	R	R	157214	9.75	9.86	10.08	K	C	C
33262	9.06	9.47	9.81	M	I	I	157792	8.78	8.87	8.94	I	I	I
34411	9.66	9.83	9.93	I	I	I	157881	9.34	(9.72)	10.10	K	A	A
37394	8.43	8.53	8.63	R	R	R	160691	9.63	9.79	9.88	I	I	I
38392	8.75	8.94	9.14	R	R	R	166620	9.64	9.86	10.08	C	C	C
38393	8.43	9.22	9.51	K	I	I	172167	8.50	8.54	8.59	I	I	I
38678	8.37	8.57	8.69	I	I	I	173667	9.33	9.38	9.40	I	I	I
39060	0	8.44	8.72	A	I	I	185144	9.63	9.74	9.84	R	R	R
43834	9.71	9.86	10.02	R	R	R	185395	8.81	9.11	9.24	I	I	I
48915	?	?	?	-	-	-	187642	9.04	9.09	9.13	I	I	I
50281	9.02	9.42	9.82	K	K&M	M	191408	9.64	9.86	10.08	C	C	C
61421	9.17	9.23	9.28	I	I	I	192310	?	?	?	-	-	-
69897	9.28	9.54	9.67	K	I	I	197692	9.14	9.30	9.39	I	I	I
74576	7.69	7.91	8.13	C	C	C	203280	8.91	8.95	8.99	I	I	I
75732	?	?	?	-	-	-	203608	9.81	10.02	10.16	I	I	I
76151	8.92	9.02	9.13	R	R	R	207129	9.64	9.78	9.92	C	A	I
81997	9.10	9.32	9.43	I	I	I	209100	8.91	9.11	9.31	R	R	R
84737	9.63	9.73	9.78	I	I	I	215789	8.71	8.73	8.76	I	I	I
88230	9.67	(9.88)	10.10	K	A	A	216956	8.02	8.35	8.53	I	I	I
90839	8.21	9.07	9.66	K	I	I	217014	9.64	9.71	9.91	C	I	I
95128	9.59	9.80	9.92	I	I	I	219134	?	?	?	-	-	-
97603	8.79	8.83	8.87	I	I	I	222368	9.51	9.58	9.67	I	I	I
100623	9.64	9.86	10.08	C	C	C							

Methods used: **I**: Isochrones; **M**: Metallicity; **R**: Roatation; **C**: Calcium; **K**: Kinematics; **R&C**: Average of the two methods R & C; **A**: Results from arbitrarily fixed maximum or minimum age.

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