THE METALLICITY DISTRIBUTION OF LATE-TYPE DWARFS AND THE HIPPARCOS HR DIAGRAM*

M. Haywood, J. Palasi, A. Gómez, L. Meillon
DASGAL, URA 335 du CNRS Observatoire de Paris - Meudon, France

ABSTRACT

The Hipparcos Catalogue provides an accurate and extensive sampling of the solar neighbourhood HR diagram. The morphology of this diagram depends on selection criteria of the catalogue such as the limiting magnitude, and on the characteristics of the stellar populations near the Sun (space density, metallicity, star formation rate, etc). We present our first results on the local stellar populations, obtained from the study of a well defined, accurate (but restricted) sample. Using a sample of G and K dwarfs, we define the local metallicity distribution of long-lived stars in the solar neighbourhood, and discuss the resulting metallicity distribution and the kinematic properties of the sample. These results will be used in a model of the local galactic stellar populations. This model is briefly presented, and will be used to analyse the accurate multidimensional data now available for the Hipparcos survey stars.

Key words: Hipparcos HR diagram; dwarfs metallicity distribution; Star Formation Rate; Initial Mass Function.

1. INTRODUCTION

The morphology of the Hipparcos HR diagram in the late type stars region depends on the metallicity distribution of stars in the disc. A detailed study of the distribution of the stars in this diagram requires the metallicity distribution and kinematical properties to be properly defined. We derive such a metallicity distribution from a distance limited sample of G and early K long-lived dwarfs. The kinematical properties of this sample are studied and its acquaintance with the classical stellar populations are discussed. The metallicity distribution will be used as an input parameter for a model of the galactic stellar populations in the solar neighbourhood.

*This work is based on the data of the ESA astrometric satellite Hipparcos.

2. METALLICITY DISTRIBUTION OF NEARBY G AND EARLY K DWARFS

2.1. Selection of a Complete Sample

We wish to calculate the metallicity distribution of long-lived stars in the solar neighbourhood, with the aim of (a) obtaining information on the local stellar populations (classical thin disc, but also possibly the metal-poorer populations), (b) establishing a new disc dwarfs metallicity distribution. In the first case one would like to sample similarly the different stellar populations, i.e. independently of any bias due to metallicity effects, limiting apparent magnitudes, etc: ideally, one would like to calculate the distribution of metallicity per unit mass interval, on the basis of a distance-limited sample. Colour or absolute magnitude selections can introduce strong bias in the distribution since stars at a given mass but different metallicity span a large range of absolute magnitudes and colours. At a given colour, subdwarfs being 1 magnitude fainter, are sampled to a distance 3 times smaller than dwarfs (Grenon 1978). A $V/V_{\max}$ test (Schmidt 1968) shows that the new set of Hipparcos parallaxes defines a sphere which is roughly complete up to magnitude $V = 9$, or $B - V = 1.3$, giving 521 stars. This is the faintest limit to which we may hope to have a complete sample of the local stellar populations. However, determination of photometric metallicity is not calibrated down to this limit (to our knowledge) in intermediate-band photometric systems for which most of these stars have been measured. We have used the Geneva photometry, which is available for 443 of the above 521 stars. Photometric metallicity has been calibrated by Grenon (1978) for $0.40 < B_2 - V_1 < 0.65$ ($0.65 < B - V < 1.05$) and by Kunzli et al. (1997) for stars with $B_2 - V_1 > 0.40$. For dwarfs, the redder limit is equivalent to $M_v \approx 6.5$, which reduces the sample to 428 stars.

2.2. Metallicity Calibration

For the calibration used for stars with $0.40 < B_2 - V_1$, we refer to Kunzli et al. (1997). For redder stars, the metallicity is related to the δ_{1256} index, defined as the difference between the $U - B$ Geneva colour index of the star and the Hyades sequence at the $B_2 - V_1$ colour of the star (Grenon 1978). Grenon (1978) has calibrated such a relation for G and early K dwarfs,

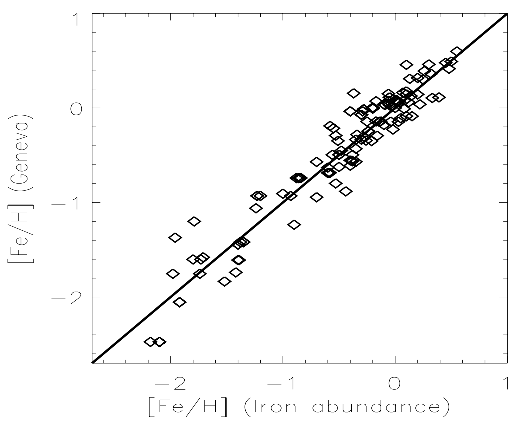

Figure 1. Photometric determination of metallicity using the calibration by Grenon (1978), versus spectroscopic measurements for dwarfs with 0.40 < B_2 – V_1 < 0.65.

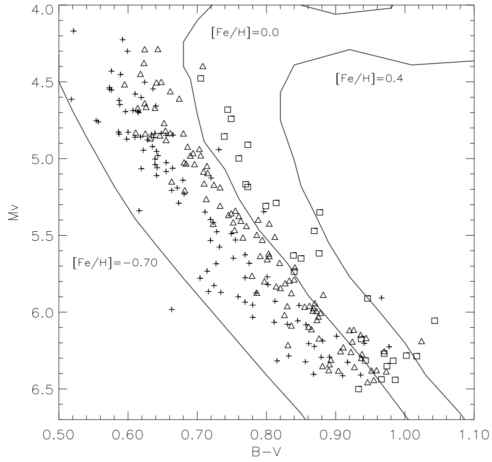

Figure 2. Colour-magnitude diagram for the stars selected. Crosses are for stars with [Fe/H] < −0.15, triangles for stars with −0.15 <[Fe/H]< +0.15, squares for stars with [Fe/H] > +0.15. The three isochrones are from Bertelli et al. (1994).

and obtained:

$$[Fe/H]_{\rm Gen} = 2.96 + 2.04/(\delta_{1256} - 0.72)$$

We have compared this calibration with more recent spectroscopic data. The result of this comparison is given on Figure 1 and shows that the correlation between the photometric metallicity and the spectroscopic iron abundance is more than satisfactory, the relation by Grenon (1978) giving a tied correlation over the 3 dex of metallicity. A line fit to the data shows that there may be a slight zero point problem, with the photometric metallicities being approximately 0.02 − 0.03 dex overestimated.

2.3. Selection of Long-Lived Dwarfs and Final Distribution

Each of the stars selected above was compared to the isochrone (Bertelli et al. 1994) with adequate metallicity, in order to retain only those stars that have sufficiently low masses that even those born in the early Galaxy are still on the main sequence. We used the parallaxes from Hipparcos and calculated the corresponding absolute magnitudes. This selection yielded 243 stars, with their positions in the HR diagram plotted on Figure 2, with rough indication of the metallicity of the stars in three different intervals.

The kinematically unweighted metallicity distribution is shown on Figure 3, together with the distribution obtained by Wyse & Gilmore (1995) which is normalised to show the same number of stars, for comparison. The two distributions peak at the same metallicity (−0.1 dex), but show important differences on both the metal rich and metal-poor sides.

In our case, 6 per cent of the sample (14 stars) have [M/H] > 0.25 dex, while these stars are non-existent in the Wyse & Gilmore sample, but this could be a statistical variation. A similar proportion have [M/H] < −0.5 dex (16 stars), whereas these represent 19 per cent in the Wyse & Gilmore sample. Hence, according to our sample, and contrary to Wyse & Gilmore, there is no over-density of the metal-poor component in the solar neighbourhood. Obviously, our sample shows that the classical relative deficit of metal-poor stars relative to the simple box model is confirmed and even more acute.

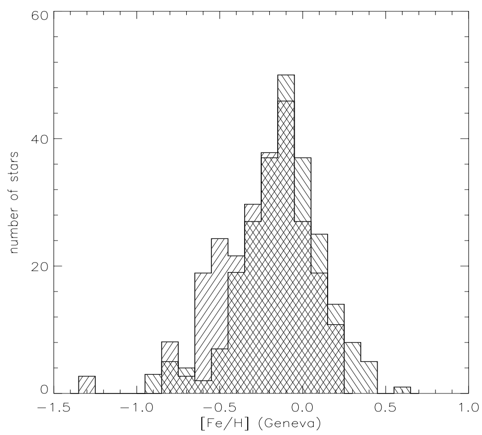

Figure 3. Kinematically unweighted metallicity distribution of long-lived dwarfs. The hatched histogram oriented on the left is for our stars. The other distribution is from Wyse & Gilmore (1995), normalised to give the same total number of stars.

2.4. Kinematic Behaviour of the Sample

U,V,W velocities were calculated for all the 243 stars in the sample. The errors in the velocity components were computed taking into account the errors on the astrometric and spectroscopic data, as well as the correlation coefficients between astrometric parameters.

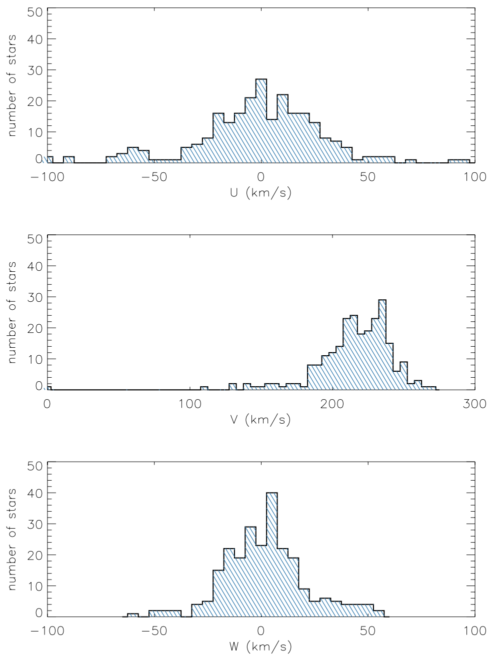

Figure 4. Histograms for the three components of the velocity.

Most of the velocities have errors less than 3 km s^{-1}, with only 5 stars having a U component error greater than 6 km s^{-1}. No W component were found to have error larger than 1 km s^{-1}.

2.4.1. Comparison with Other Studies

Figure 4 shows the histograms for each velocity component. The dispersion along the three axis is 29.4 ± 1.3, 24.9 ± 1.1, 19.4 ± 0.9 km s^{-1}. Overall, the sample selected is rather kinematically cold. This result is confirmed on the starting set of 520 stars, giving slightly lower values: (26.4 ± 0.8, 21.4 ± 0.7, 17.1 ± 0.7) km s^{-1}. For the metal-poor part of our sample, dispersions are of the same order as those found by Flynn & Morel (1997) (45 ± 12, 44 ± 11, 35 ± 9) for 16 stars with $-1.0 <$ [Fe/H] < -0.6: 39.2, 44.1, 30.1 km s^{-1}.

These results are however significantly different than those given by Wyse & Gilmore (1995), whose sample was constructed with stars included in the 25 pc sphere according to the last version of the Catalogue of Nearby Stars (Gliese & Jahreiss 1991). For 86 stars for which we had kinematic data in the Wyse & Gilmore sample we calculated 44.5 ± 3, 33.2 ± 2.5, 31.6 ± 2.4 km s^{-1}, using the Hipparcos parallaxes. However, it appears that 39 stars, or 43 per cent of their sample is outside the 25 pc limit according to the new Hipparcos distances. If we select only those stars that are nearer than 25 pc, dispersions are 33.5 ± 3.4, 36.1 ± 3.7, 23.5 ± 2.3 km s^{-1} for the 48 remaining stars. Residual differences with our values may come from the way long-lived stars were selected in each sample, and from the fact that other stars

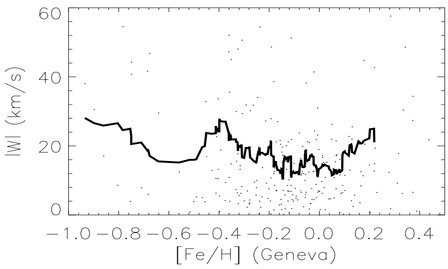

Figure 5. Running standard deviation of the vertical velocity component for sample stars. The standard deviation is calculated over 16 stars.

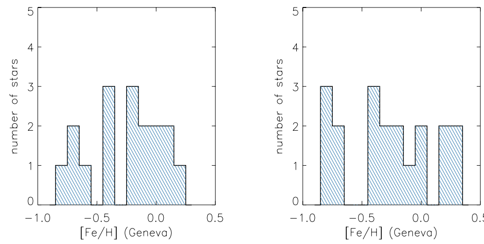

Figure 6. (a) Metallicity distribution for the 16 stars lagging with V< 180 km s^{-1}, (b) Metallicity distribution for the 18 stars outside the 2 σ_W limits of Figure 5.

where excluded by error from their sample. On the other hand, stars outside the 25 pc in the Wyse & Gilmore sample were found to have much hotter kinematics (55.7, 29.0, 39.8) km s^{-1}. Plotting the colour magnitude diagram for these stars shows that they are all subgiants, misclassified dwarfs included into the 25 pc sphere due to the erroneous spectroscopic or photometric parallaxes.

2.4.2. Where has the Thick Disc Component Gone?

Interesting features are suggested by Figure 5. First, at solar metallicity, representative of disc stars, the W dispersion is quite low at a level of approximately 15 km s^{-1}. The fact that the σ_W component has been overestimated had already been suggested by Strömgren (1987), and it is confirmed here (see also Gómez et al. 1997). Most striking however is the overall very small value for this dispersion on the whole metallicity scale. At [Fe/H] < -0.3 one would expect the thick disc to slowly overcomes the distribution. However only a slight increase to 30 km s^{-1} is observed (first point of the running standard deviation calculated over 16 stars). This suggests that the thick disc component has a lower local density than suggested by star-counts models (Robin et al. 1996).

The composite nature of the kinematically hot component is confirmed by Figure 6, which shows that part of the stars lagging the local standard of rest have metallicities typical of the disc component. This is also confirmed when the selection is made on the stars having the highest vertical velocities (Figure 6 (b)).

On the metal rich side, the dispersion also increases to approximately 21.5 km s^{-1}, suggesting the presence of a hotter and metal-rich component as advocated by Grenon (1989).

3. MODELLING THE HIPPARCOS HR DIAGRAM

The Hipparcos survey, designed to be a complete magnitude-limited sample in the Input Catalogue, is well suited to make direct comparisons with models of the galactic stellar populations. However, the new Hipparcos catalogue provides accurate multidimensional data requiring complex modelling that takes into account the new observational parameters available for all the stars, such as the new Hp magnitudes, Tycho colour, parallaxes, binaries information, etc., and also the complex physical dependence between these parameters. As a first step for such study, we briefly describe our model, and show first comparisons with the Hipparcos survey.

3.1. Brief Description of the Model

The last version of the model has been described in Haywood et al. (1997). It has been further refined to take into account the high quality data now available with Hipparcos. The model describes the HR diagram using evolutionary tracks at different metallicities, and for each star generated, calculates its characteristics by linear interpolation between the tracks. The model contains the three classical stellar populations namely the thin disc, the thick disc and the halo. The adopted characteristics for these three populations are given in Haywood et al. (1997). The model also accounts for binaries, the percentage of systems, the IMF of the companions, the distribution of separation are given as free parameters to be determined by comparisons with the data.

3.2. Calibration of the Hipparcos and Tycho Magnitudes

Calibration of the bolometric corrections for the M_H Hipparcos and M_{V_T} Tycho absolute magnitudes and colour were obtained using a set of approximately 250 and 800 stars with metallicity taken from the literature. Relations were calculated for dwarfs and giants of both solar and deficient metallicities. The resulting relations are plotted on Figure 7 for the bolometric M_H magnitude and $B_T - V_T$ colour, for solar-metallicity dwarfs and giants. These calibrations will be published elsewhere (Haywood, in preparation).

3.3. Synthetic HR Diagram

These calibrations were used to construct synthetic HR diagrams, and to compare them with the Hipparcos survey. An example of such synthetic HR diagram is shown on Figure 8. We'll present elsewhere extensive comparisons between this model and the Hipparcos Survey.

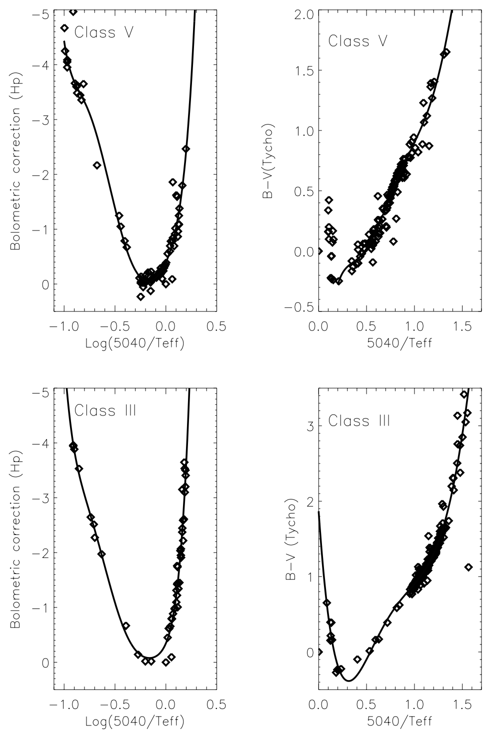

Figure 7. Example of bolometric corrections for disc-abundance dwarfs in the Hipparcos band, luminosity class V and III and calibration of the Tycho $B_T - V_T$ as a function of $5040/T_{\rm eff}$ for dwarfs and giants.

4. CONCLUSIONS

With the new accurate parallaxes provided by the Hipparcos satellite mission, stellar populations in the solar neighbourhood can be well defined on the basis of distance-limited samples. We have selected such a sample within 25 pc, containing G and early K dwarfs. The metallicity distribution derived using the Geneva photometry shows that previous distributions have overestimated the metal-poor tail ([Fe/H]< -0.5 dex) and underestimated the metal rich one (Fe/H]> 0.25 dex), which now represents similar proportions (approximately 6 per cent) of stars locally. The whole sample has a kinematics akin to the old disc stellar population. Stars with [Fe/H]< -0.5 dex do not have the kinematic characteristics expected for pure thick disc population, implying that the local thick disc population has density less than 6 per cent. These results confirm the relative deficit of metal-poor stars in the solar neighbourhood. The existence of a metal rich component is confirmed (Grenon 1989), however there is no evidence in our sample that these stars have a kinematical behaviour different from disc stars.

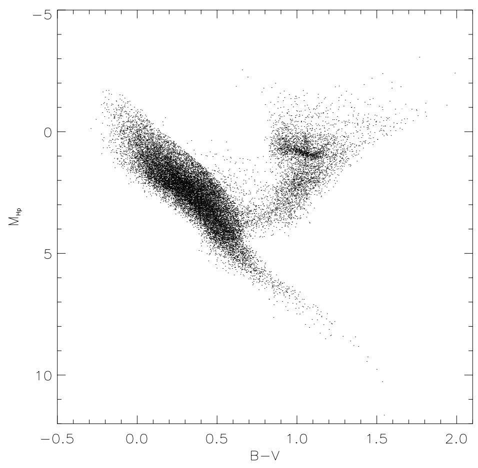

Figure 8. Simulated HR diagram.

REFERENCES

Bertelli, G., Bressan, A., Chiosi, C., Fagotto, F., Nasi,E., 1994, Astron. Astrophys. Suppl. Ser. 106, 275

Flynn, C., Morel, O., 1997, MNRAS, 286, 617

Gliese, W., Jahreiss, H., 1991, Third Catalogue of Nearby Stars

Gómez, A.E., et al., 1997, ESA SP–402, this volume

Grenon, M., 1978, Publication de l'Observatoire de Genève

Grenon, M., 1989, Astro. Space Sci., 156, 29

Haywood, M., Robin, A., Crézé, M., 1997, A&A, 320, 428 & 440

Kunzli M., North P., Kurucz R.L., Nicolet, B., 1997 A&AS, 122, 51

Robin, A.,C., Haywood, M., Crz, M., Ojha, D.,K., & Bienaym, O., 1996, A&A, 305, 125

Strömgren B., 1987, The Galaxy, eds Gilmore G. & Van der Kruit, P.

Schmidt, M., 1968, ApJ, 151, 393

Wyse, R.F.G., Gilmore G., 1995, AJ, 110, 2771