THE HR DIAGRAM OF METAL-DEFICIENT STARS*

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ABSTRACT

Observational HR diagrams in the M_V, $B-V$ plane have been constructed for about 150 Hipparcos-parallax stars of field Population II having σ_π/π values less than 0.20. The sample treated is representative of main sequence, turn-off, subgiant, giant and HB stars with metal deficiency varying from moderate to extremely low [Fe/H] values. As a result of the improvements in absolute magnitudes, we find that a considerable fraction (about 40 per cent) of F–G stars classified earlier as subdwarfs are subgiants. Based on comparison of our observational loci with globular cluster fiducials and theoretical isochrones, an age spread of 7±2 Gyr is found among halo stars, which is similar to that detected recently among halo globular clusters. Some results obtained from the Hipparcos-based kinematics of metal-deficient field stars are also presented.

Key words: stars: Population II: age; HR diagram.

1. INTRODUCTION

The sample of 455 metal-deficient stars proposed for the Hipparcos program by one of the authors (Bartkevičius 1994, Proposal No. 57) was composed of local subdwarfs, giants, RHB, and CH stars covering the metallicity range from moderate to extremely low [Fe/H] values. These stars were selected from various then-existing (1982) catalogues and lists of metal-deficient or suspected metal-deficient stars, compiled mainly by Bartkevičius (1980, 1982). The proposed program was primarily aimed at deriving the location of subdwarf sequences of different metallicity in the HR diagram and determining ages of nearby halo stars of the turn-off region. The secondary goal was to obtain the Hipparcos-based kinematics of a metal-poor stellar population in the solar neighbourhood and to perform more accurate luminosity calibration of the Vilnius photometric system.

In this paper we present preliminary results obtained within the above framework of the proposed program.

*Based on data from the ESA Hipparcos astrometry satellite.

2. BASIC DATA

444 stars of the proposed program have been observed by Hipparcos, but of these, only 83 have parallaxes measured to better than $\sigma_\pi/\pi = 0.10$. The number of stars with $\sigma_\pi/\pi \leq 0.20$ amounts to 151. However, errors in parallaxes exceeding 10 per cent give rise to substantial uncertainties in the treatment of the observational HR diagram and we used such stars with reservations. Program stars with Hipparcos parallaxes of lower accuracy ($\sigma_\pi/\pi > 0.20$) were rejected from further study.

The absolute magnitudes derived from parallaxes have been corrected for the Lutz & Kelker (1973) systematic bias, using the approximation formula of Hanson (1979) with the exponent $n = 2.5$. For stars with σ_π/π values involved in the present study, $\leq$0.10 and $\leq$0.14, these corrections amount to only –0.07 and –0.14 mag, respectively.

Along with the astrometric data, the values of V and $B-V$ were taken from the Hipparcos Catalogue (ESA 1997). Magnitudes and color indices have been corrected using the reddenings derived by averaging of published values. The metallicity values used in our work are also averages over several sources, mainly over those of high-dispersion analysis.

Seven of the stars treated are unresolved binaries, and we computed the positions of their components in the M_V, $(B-V)_0$ diagram down the appropriate isochrone.

3. THE METAL-POOR MAIN SEQUENCE

The primary goal of the proposed program was to provide an empirical definition of the position of the main sequence for different abundance ranges. Despite the fact that a large fraction of subdwarfs has initially been admitted to our proposed sample of stars, Hipparcos results, however, diminished this fraction considerably. As a result of the improvements in absolute magnitudes, we find 40 per cent of the F–G stars classified spectroscopically (mainly from intermediate-dispersion spectra) and/or photometrically as subdwarfs to be subgiants. Therefore,

the main sequence region of the observational HR diagram remains defined by a much smaller number of data than expected.

Figure 1 exhibits the M_V, $(B-V)_0$ diagram for metal-deficient main sequence stars with parallaxes accurate to within 10 per cent. The principal feature to note in this figure is a comparatively small separation in absolute magnitude over the range of [Fe/H] from -1 to -2. There is a suggestion in Figure 1 that, within the errors, all metal-poor ([Fe/H]<–1) stars exhibit the same main sequence.

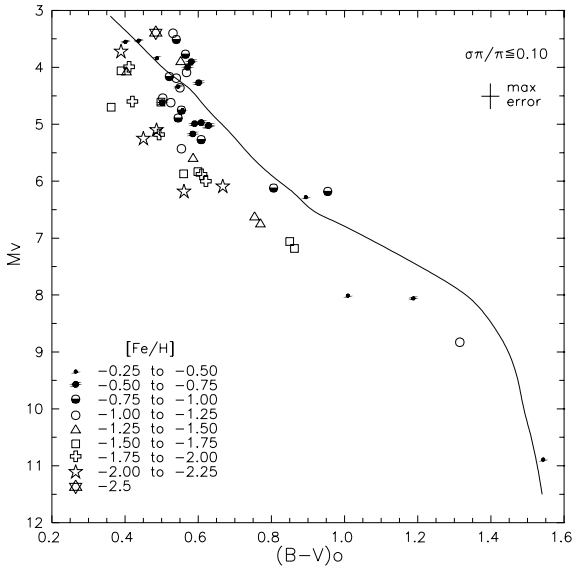

Figure 1. M_V, $(B-V)_0$ diagram for metal-deficient stars with Hipparcos parallaxes accurate to within 10 per cent. Solid line is the main sequence of normal chemical composition stars from Straižys (1992).

4. COMPARISON WITH GLOBULAR CLUSTER FIDUCIALS

Observational loci of our stars have been matched against fiducials of four less-reddened globular clusters of different metallicity: 47 Tuc ([Fe/H] = −0.7, E_{B-V} = 0.04 mag), M5 ([Fe/H] = −1.4, E_{B-V} = 0.03 mag), M13 ([Fe/H] = −1.65, E_{B-V} = 0.02 mag, and M68 ([Fe/H] = −2.0, E_{B-V} = 0.07 mag). The globular cluster data on fiducial sequences, metallicity, and reddening were taken from the following papers: for 47 Tuc, from Hesser et al. (1987), for M5, from Sandquist et al. (1996) and Richer & Fahlman (1987); for M13, from Richer & Fahlman (1986) and Sandage (1970); for M68, from McClure et al. (1987). For the subdwarf main-sequence fitting we used the Hipparcos stars with $\sigma_\pi/\pi \leq 0.10$ and metallicities [Fe/H] deviating from the cluster values not more than 0.2 dex. Therefore, there was no need to adjust the stars to the same abundance (the color corrections should not exceed 0.01 mag).

Shown in Figures 2 and 3 are the main-sequence fitting diagrams for two of the clusters considered, 47 Tuc and M5, together with theoretical isochrones

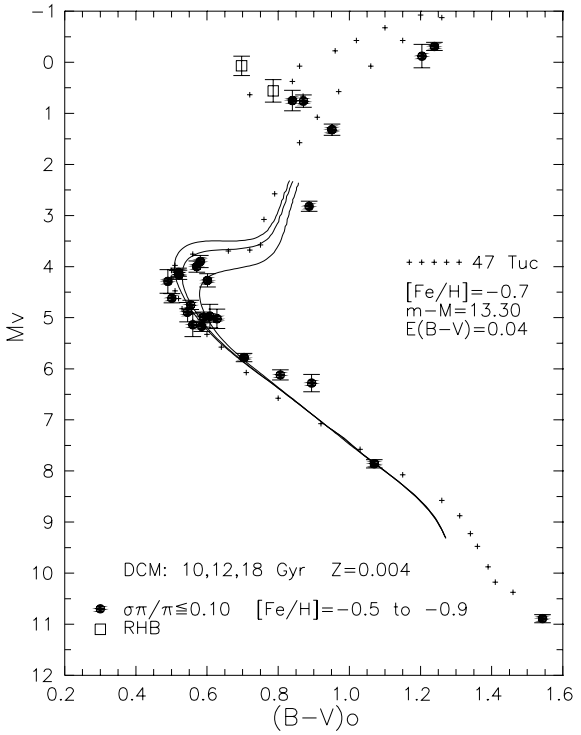

Figure 2. Main sequence fitting diagram M_V, $(B-V)_0$ for 47 Tuc.

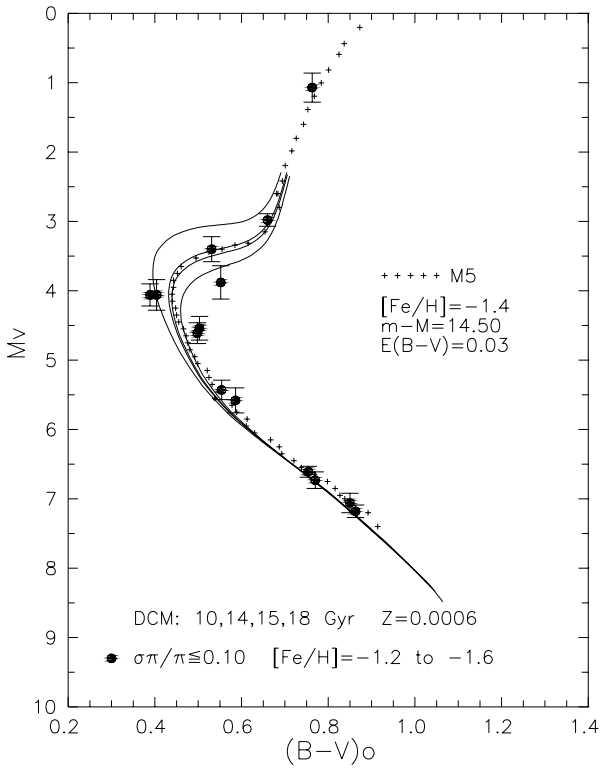

Figure 3. Main sequence fitting diagram M_V, $(B-V)_0$ for M5.

of the D'Antona et al. (1997) (DCM) model in which the external convection is treated using a full scale turbulence (FST) analysis. As is apparent from the figures, we have the satisfactory results of the main-sequence fitting. The apparent distance moduli 13.3 and 14.5 mag we arrive at for 47 Tuc and M5, respectively, do not significantly differ from those derived by other authors (see Hesser et al. 1987, Sandquist et al. 1996, Reid 1997). There is also a large body of evidence that some of the field halo stars are somewhat older than the globular clusters considered and that halo stars of similar metallicity show a considerable spread in their turn-off color, what is likely to lead to an appreciable age spread.

5. THE AGE SPREAD AMONG HALO STARS

In Figure 4 we plot the M_V, $(B-V)_0$ diagrams, together with the set of FST model isochrones of D'Antona et al. (1997). The metallicities of stars in each diagram differ from the central isochrone-values by not more than 0.15 dex, a typical error in [Fe/H] determination. Examination of the figures shows that all of our Hipparcos-based turn-off samples are well bracketed by the 10–20 Gyr isochrones, nearly independently of the metallicity range considered. Assuming for the standard deviation of a single age determination a round value of 2 Gyr (if the errors in M_V and $(B-V)_0$ are the only contributors to the age error), we thus conclude that the average age spread among halo stars is 7 ± 2 Gyr. This value is similar to that detected recently among halo globular clusters (Chaboyer et al. 1996).

6. KINEMATICS OF THE METAL-POOR POPULATION

Table 1 presents the mean kinematic parameters (i.e., the velocity dispersions and the mean rotation velocity) for two metallicity ranges: $-0.4 >$[Fe/H]> -1.1 and [Fe/H]≤ -1.2. These results are based completely on the Hipparcos parallaxes and proper motions. Only Hipparcos stars with $\sigma_\pi/\pi \leq 0.20$ and known radial velocities were used in kinematic calculations. The rotation velocity $\langle V_{\rm rot} \rangle$ is given adopting 220 km s^{-1} for the circular velocity of the Sun relative to the external frame. The results for stars with [Fe/H] from –0.4 to –1.1 ($N = 39$) appear to be quite consistent with those attributed to the 'Gilmore & Wyse' thick disk, the kinematics of which are dominated by rotational support. The kinematic parameters of stars with metallicity [Fe/H]$\leq$–1.2 ($N = 64$) are consistent with those of the pressure supported halo population. On the whole, the mean kinematic parameters do not significantly differ from earlier results.

Table 1. Mean kinematic parameters of the Hipparcos stars with $\sigma_\pi/\pi \leq 0.20$.

[Fe/H] range	$\langle V_{\rm rot} \rangle$ (km/s)	σ_U (km/s)	σ_V (km/s)	σ_W (km/s)	N
–0.4 to –1.1	188±8	68±7	50±4	41±5	39
–1.2 to –2.5	21±13	177±13	105±11	82±12	64

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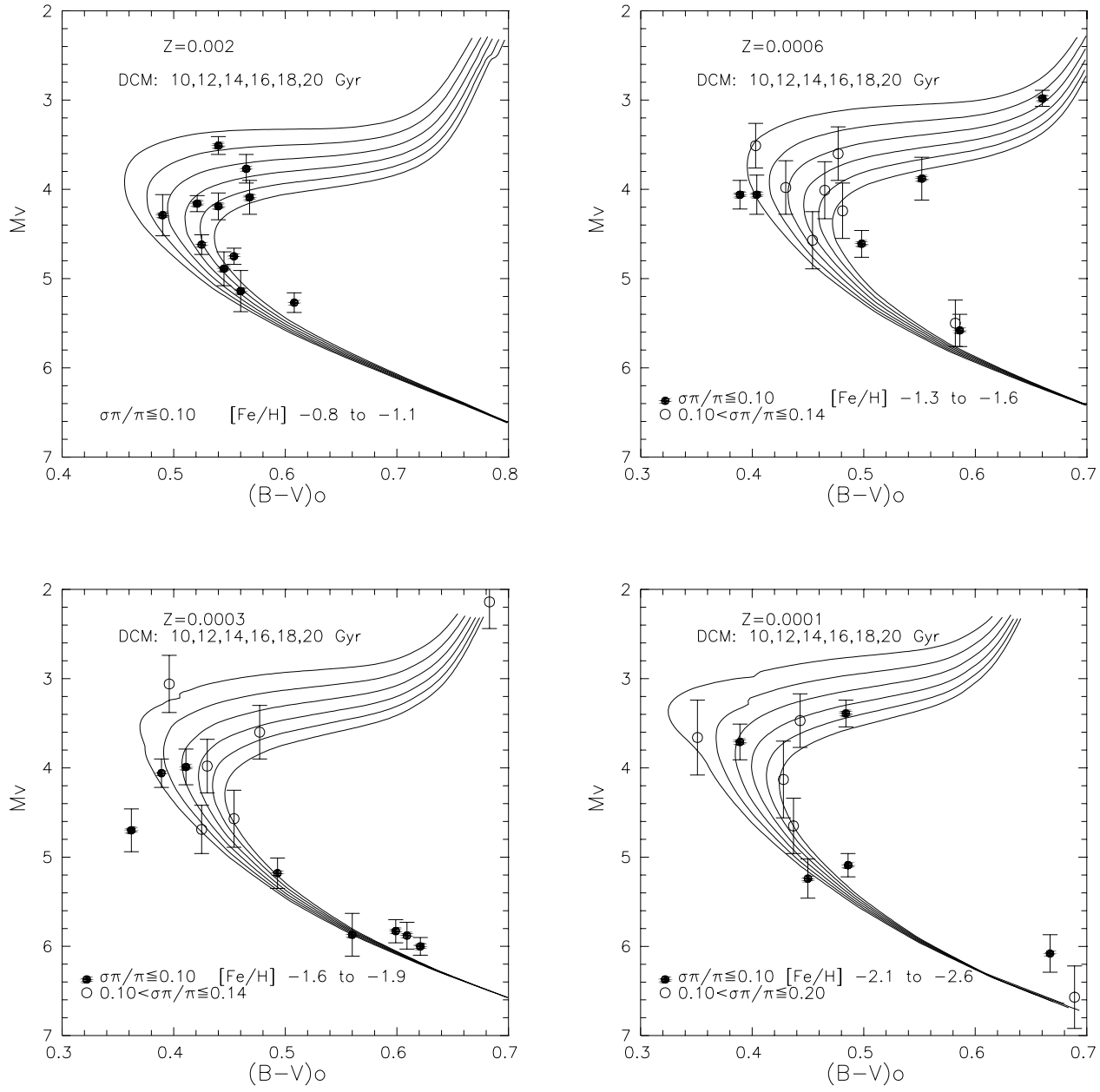

Figure 4. M_V, $(B-V)_0$ diagrams for the turn-off region stars. Isochrones are of D'Antona et al. (1997) FST models.