Biases in the Main Sequence Fitting Distances to Globular Clusters based on the Hipparcos Catalogue

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Abstract. We discuss the different biases affecting the sample of field subdwarfs selected from the Hipparcos Catalogue, and used in the Main Sequence Fitting technique to derive distances to Galactic Globular Clusters. The adopted average corrections significantly affect the derived distance moduli, explaining the differences among various groups using this technique.

1. How many biases? How large is their effect?

Several biases affect the derivation of distances to globular clusters (GCs) via Main Sequence Fitting method. However, their impact can be rather different, depending on how the field subdwarfs used to build up the template sequences are selected.

In a a priori selected sample, selection criteria do not rest on parallaxes, but on other constraints such as the metal abundance of the subdwarf sample (Gratton et al. 1997, G97; Reid 1997, 1998, R97, R98; Carretta et al. 1998, C98; a subset of the sample in Pont et al. 1998, P98). It is usually easy to correct for biases, in this case, since selection criteria are rather well defined by the investigators themselves.

In a a posteriori selected sample, objects are extracted from the colour-magnitude diagram of the whole HIPPARCOS catalogue, for instance selecting stars within a given range of $M_V$ (i.e. parallax) and colour (i.e. metallicity, with metal abundances derived from colours; the second subset of stars used by P98). Selection criteria are rather poorly defined in this case, and it is much more difficult to correct for biases.

Major systematic effects affecting the Main Sequence Fitting technique are listed in Table 1 and briefly reviewed below.

(a) Malmquist bias – In magnitude limited samples (with a range in luminosity) observational errors produce a bias toward luminous objects. In
Table 1. Systematic effects to be considered

| Effect                          | \( \Delta(m - M) \) (C98) |
|---------------------------------|-----------------------------|
| Malmquist bias                  | negligible                  |
| Lutz-Kelker                     | \( \pm 0.02 \)              |
| Metallicity bias                | depends on the sample       |
| Binaries (in the field)         | \( \pm 0.02 \)              |
| Binaries (in clusters)          | \( \pm 0.03 \)              |
| Non solar abundance ratios      | negligible                  |
| Photometric calibrations        | \( \pm 0.04 \) (mean value from 9 GCs) |
| Reddening scale                 | \( \pm 0.07 \)              |
| Metallicity scale               | \( \pm 0.08 \)              |
| Total uncertainty (1\( \sigma \)) | \( \pm 0.12 \) (at least...) |

In turn, the average absolute magnitude is systematically overestimated. Corrections are negligible in G97 and C98 where the distribution in \( M_V \) is narrow (only unevolved main sequence stars were used). The effect, however, must be considered in R97 and P98, whose samples include also stars brighter than the turn-off.

(b) Lutz-Kelker effect – If stars are selected using parallax as a criterion and/or are weighted in the sample according to the ratio \( \sigma_\pi/\pi \), average parallaxes are overestimated. Corrections strongly depend on \( \sigma_\pi/\pi \), and on the parallax distribution of the original population, which is not known, but can be estimated from the proper motion distribution (see Hanson 1979), as done in R97.

Care should be taken when Lutz-Kelker corrections are large. A Montecarlo approach should be preferred in these cases (G97, P98). However, the safest procedure is to use only stars with good parallaxes \( (\sigma_\pi/\pi < 0.12) \), since corrections are small \( (< 0.02 \text{ mag for the weighted average of the sample in C98}) \).

(c) Metallicity bias – Since the metallicity distribution of the stars in the solar neighbourhood is strongly skewed toward solar values, when colours are used to extract a sample of metal-poor stars from the Hipparcos catalogue, random errors will increase the number of metal-rich stars erroneously measured too blue with respect to the number of metal-poor stars measured too red. This is further complicated due the non-gaussian distribution of the errors taken from Tycho catalogue. This metallicity bias affects only samples derived \( a \ posteriori \) (the second sample in P98).

(d) Binaries (in the field) – A too long distance scale will be derived if the local subdwarf sample is contaminated by unresolved binaries, since the combined systems would be redder and brighter. The safest approach is to use only \( bona fide \) single stars (G97, C98). However, corrections may be required, since some residual undetected binary may escape detection. It is not easy to derive accurate binary corrections, since they depend on rather uncertain parameters: (i) the actual incidence of binaries and (ii) the distribution in mass (or luminosity) of the secondary components.

P98 assumed that half of the stars are binaries, and that the correction for each binary is, on average, half the maximum value. The net result was a rather large estimate of 0.18 mag for this correction, applied to known and suspected binaries, as well as to \( bona fide \) single stars.
G97 compared binaries and *bona fide* single stars: from the average offset of the colours and the scatter around it they derived an average correction for each binary of $0.16 \pm 0.05$ mag, and a fraction $p \leq 0.16$ of undetected binaries in their subdwarf sample (beside the 41% of stars which are known or suspected binaries). The average binary correction derived by G97 (to be applied only to *bona fide* single stars) is of $0.02 \pm 0.01$ mag.

**(e) Binaries (in globular clusters)** – If contamination by binaries is present in the main sequence of a GC, a too short distance scale will be derived.

Binary incidence is likely to be higher in the field, where multiple systems have higher probability to survive disruption. However, blending of unrelated stars due to the extreme crowding conditions typical of GCs, has the same photometric effect of physical binarity. To reduce this problem, the usual approach is to use modal rather than mean values to identify the main sequence mean loci of globular clusters.

**(f) Photometric calibrations** – The main sequence is a rather steep relation between colour and magnitude [4 < $dV/d(B-V)$ < 7 for unevolved dwarfs]. Therefore, very accurate photometric data are required, since any error in the intrinsic colours of either sequences translates into (large) errors in the derived magnitudes.

In principle field and cluster stars should be observed with the same instrumental set up and on the same photometric system. But the much brighter field stars are usually observed with photomultipliers, while data for GCs are obtained with CCDs, and their magnitudes transformed to the chosen system by means of standard stars. Uncertainty in the derived transformations may result in quite large errors (from 0.02 up to 0.04 mag) for individual clusters. For instance, an offset of 0.04 mag exists in the MS colour of M92 (the only cluster considered in P98) between Heasley & Christian (1991) and Stetson & Harris (1988). This by itself implies an uncertainty of about 3-4 Gyr in the age derived for this cluster. A safer approach is to average results over a large number of clusters (see R97, R98, G97, C98).

**(g) Reddening scale** – A uniform scale should be used for field subdwarfs and GC stars. Two reddening scales have been used for the subdwarfs: R97, G97 and C98 used reddening estimates from Carney et al. (1994), Schuster & Nissen (1989), and Ryan & Norris (1991), while reddenings used by P98 (from Arenou et al. 1992) are on average 0.016 mag larger, resulting into a shorter distance scale. For the GC reddenings, however, all authors used the same scale (Zinn 1980).

If one compares adopted data with cosecant-laws for reddening, GCs and subdwarfs result on a uniform scale if the scale-height of the galactic dust disk is 100 pc, for the reddenings adopted by G97, C98 and R97, and 40 pc if the values by P98 are used. Since the former value is in good agreement with current determinations of the galactic dust scale-height, while the latter is at the lower extreme of the admitted range, the reddening scale for subdwarfs has to be considered still quite uncertain ($\pm 0.015$ mag).

**(h) Metallicity scale** – A systematic difference of 0.1 dex in the metallicity scale adopted for subdwarfs and GCs translates into an error of $\sim 0.07$ mag ($0.03$ mag at $[\text{Fe/H}]=-2$, and 0.11 mag at $[\text{Fe/H}]=-1.0$, see G97 and C98 for details).
A uniform abundance analysis has already been used by G97, R98 and C98; however, since abundances for GCs are derived from giants rather than dwarfs, some differential effect (∼0.1 dex) cannot be excluded. High dispersion analysis of dwarfs and turn-off stars in GCs would be crucial, but this test must wait for high resolution spectrographs mounted at 8 m class telescopes (UVES at VLT).

(i) Non solar abundance ratios – The overabundance of α−elements found in metal-poor stars means that extra electron-donors (hence, additional electron pressure) are available, as well as a larger blanketing. Clementini et al. (1998) made some estimates scaling the abundances in the stellar model atmospheres, usually solar scaled, for this overabundance of electron donors (i.e. the metallicity of the model atmosphere was scaled down as [(Mg+Si+Fe)/H]). On the Fe I lines usually adopted for abundance analysis the effect turned out to be quite small (∼0.02 dex).

2. Summary and conclusions

The advent of the Hipparcos parallaxes has allowed to strongly improve the GCs Main Sequence Fitting Technique: the major contribution to the total error budget has moved from parallaxes to photometric calibrations, reddening and metallicity scale. But, despite the invaluable contribution of the Hipparcos results, the Main Sequence Distances to Galactic Globular Clusters still suffer from a total uncertainty of ±0.12 mag at least. Therefore, presently, neither the short nor the long distance scale can be completely ruled out.

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