THE TROUBLE WITH ISOCHRONE AGES FOR FIELD STARS: A CAUTIONARY TALE FOR SOLAR NEIGHBOURHOOD STUDIES

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ABSTRACT

Computing ages from theoretical isochrones for large numbers of field dwarfs is becoming standard practice to study the history of the Galaxy from the solar neighbourhood record. Ages are usually read off the nearest model isochrone in parameter space. In the wake of the publication of the Geneva-Copenhagen Solar Neighbourhood Survey, we have reconsidered the isochrone age method. We find that isochrone ages for field dwarfs are subject to enormous systematic biases, and simple analysis methods e.g., scatter plots, are not appropriate. More evolved statistical treatments are essential for meaningful results (Bayesian estimates, inverse approach).

Key words: Methods: statistical; Stars: evolution; Stars: fundamental parameters; Hertzsprung-Russell (HR) diagram; Galaxy: evolution.

1. THE GALACTIC AGE-METALLICITY RELATION

Figure 1 shows the mode of the *isochrone maximum-likelihood age* as a function of metallicity for stars in the Geneva-Copenhagen solar neighbourhood survey (Nordström et al. 2004), in a typical representation – scatter plot without error bars. Such a representation is subject to *very large systematic biases* and gives little indication on the actual age-metallicity structure of the data. The strongest of these systematic effect is the 'terminal age bias' that tends to pull all ages towards the end-of-main-sequence lifetime. It is due to the interaction of the observational uncertainties with the strongly varying speed of evolution of stars in the temperature-luminosity diagram. It tends to scatter objects into the high-age part of any age-metallicity diagram. This effect is illustrated in Figure 2. A shift between the temperature scale of the models and the observations causes all computed isochrone ages to be very near the end of the main-sequence lifetime for the corresponding masses. This spurious effect invalidates any conclusion built on such isochrone ages. For more details see Pont & Eyer (2004), Haywood (2005).

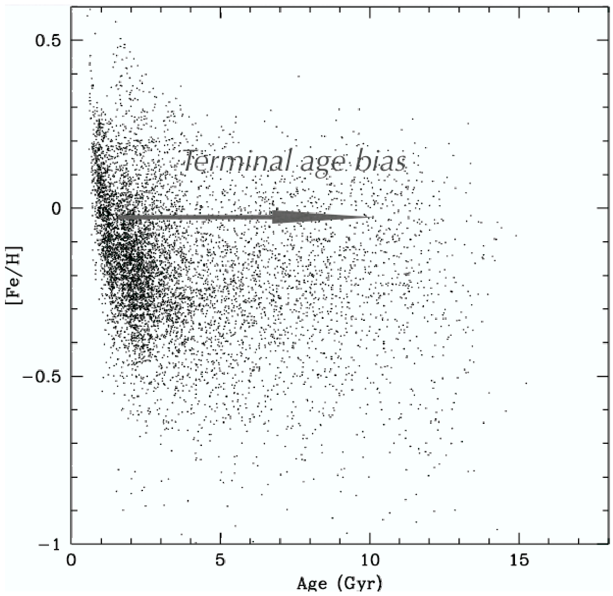

Figure 1. Isochrone maximum-likelihood age vs. metallicity for objects in the Geneva-Copenhagen survey. This kind of plot is often presented as 'the age-metallicity relation of the Galaxy'. However, it is dominated by systematic biases and bears only scant relation with the actual distribution.

2. THE EDVARDSSON ET AL. 1993 SAMPLE REVISITED

New data, mainly Hipparcos parallaxes and binarity information, on the classic Edvardsson et al. (1993) sample of $\sim$ 200 F stars show that the isochrone ages were subject to exactly the type of bias expected (see Figure 3). Many objects were scattered by the uncertainties towards higher apparent ages.

A renewed analysis (second part of Pont & Eyer 2004) shows that the main conclusion inferred from their 'Galactic AMR plot' – the near absence of definite age-metallicity relation – may in large part be due to the statistical properties of the isochrone age determination itself.

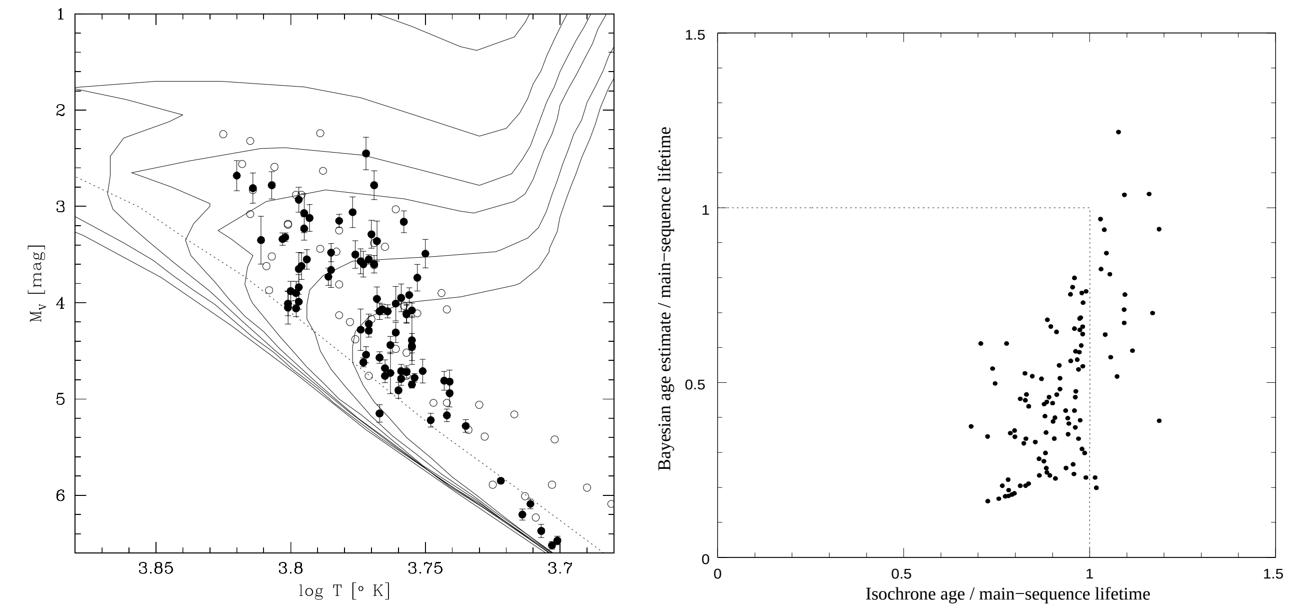

Figure 2. The ‘terminal age bias’ at work: The plot at left shows the metal-poor stars in Nordström et al. (2004) in the temperature-luminosity diagram with Padova isochrones. Open circles are known binaries. In the plot at right, the computed individual isochrone ages are shown as a function of the main-sequence lifetime, for the isochrone ages, and for Bayesian age estimates that attempts to compensate the biases. All stars are given an isochrone age near the end of main-sequence lifetime. This is of course a spurious effect, that very strongly biases isochrone ages and makes the interpretation very tricky for large samples.

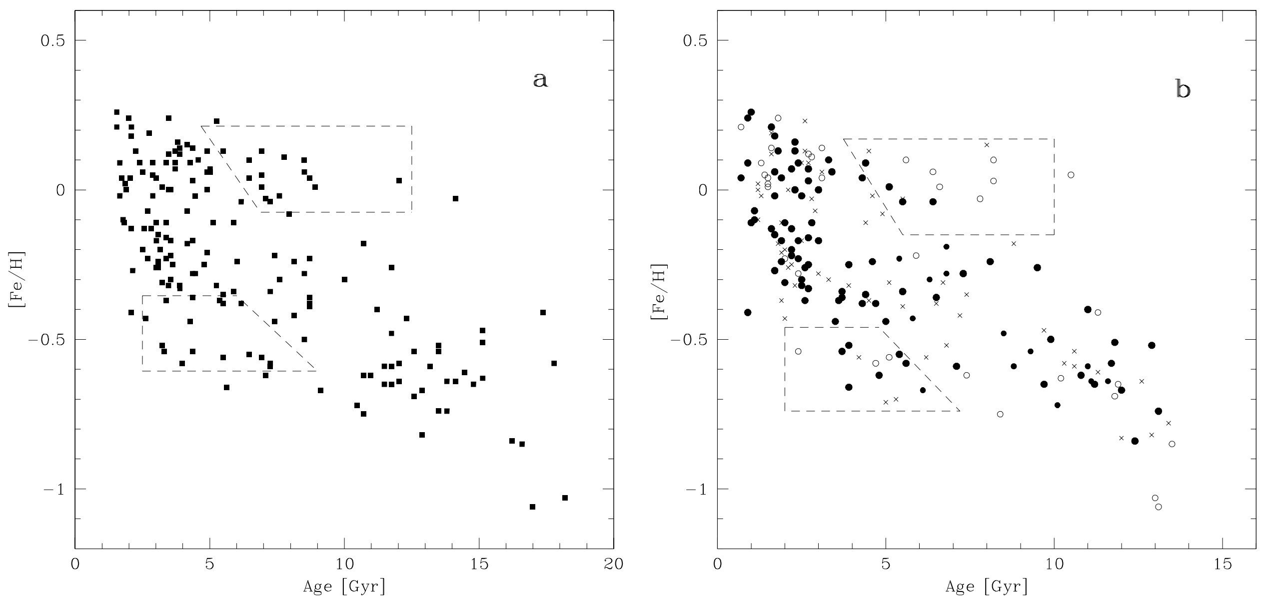

Figure 3. The ‘terminal age bias’ on the Edvardsson et al. sample: The original Edvardsson et al. age-metallicity plot [left] is compared to the plot with updated data [right]. Almost all objects originally situated in the upper box turned out to have erroneous distances or to be binaries.

3. HOW RELIABLE ARE ISOCHRONE AGES: THE 'AGE-METALLICITY RELATION OF THE HYADES'

Figure 4 shows the isochrone age versus metallicity plot for stars belonging to the Hyades cluster in the Geneva-Copenhagen catalogue. This figure is a striking illustration of the extent of the terminal age bias. From such a plot, one would tend to conclude that stars in the Hyades cluster span the whole lifetime of the Galactic disc in age, and indicate the presence of an old, metal-rich populations, with a mean age for Hyades stars near 4 Gyr! Of course, these conclusions would be absurd. Hyades stars share a common age near 0.7 Gyr, an age that can be determined if the whole cluster sequence is compared with model isochrones. In reality, the uncertainties and biases on isochrone ages are simply too large for such an age-metallicity plot to be a useful analysis tool.

4. HOW DO THESE BIASES BEHAVE: THE CEPHEID PERIOD-LUMINOSITY RELATION FROM HIPPARCOS PARALLAXES

Trigonometric parallaxes are subject to statistical effects very similar in essence to the ones affecting isochrone ages: the prior distribution in parameter space is very skewed and leads to strong Lutz-Kelker-type biases as soon as the relative error (σ_π/π) gets large.

Lutz-Kelker effects are very clear, for instance, in Hipparcos distances for Galactic cepheids (see Figure 5).

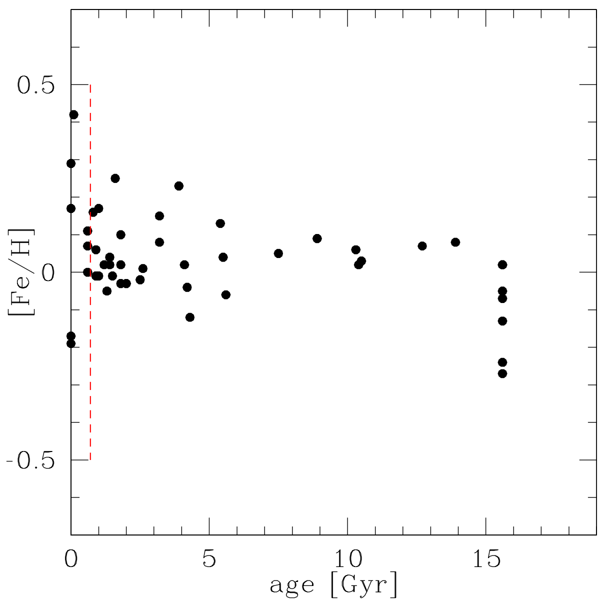

Figure 4. The 'age-metallicity relation of the Hyades': Plot of isochrone ages derived from the Geneva-Copenhagen catalogue versus metallicity for stars in the Hyades open cluster, showing the drastic effect of large uncertainties and bias on the age determination. In reality, all ages are identical at $t \sim 0.7$ Gyr (dashed line).

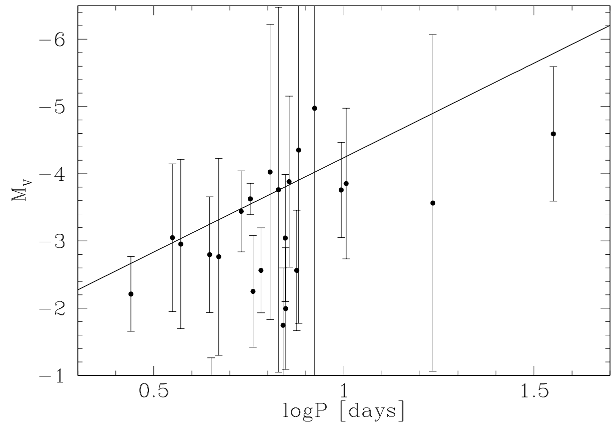

Figure 5. The 'Hipparcos Cepheid period-luminosity relation': Galactic cepheid data in the period-luminosity plot with distances calculated directly from Hipparcos trigonometric parallaxes ($d = 1/\pi$). The line shows the best-fit PL relation using a correct statistical treatment (Feast & Catchpole 1997). The Lutz-Kelker bias pushes many points far below the relation. In such cases, scatter plots and eyeball analyses lead to completely erroneous results. Figure adapted from Madore & Freedman (1998).

In the wake of the Hipparcos mission, a finer understanding of this type of biases has emerged among Galactic astronomers. In particular, it has become clear that *scatter plots and ordinary least squares are not suitable analysis tools in such cases*.

5. CONCLUSION

Lessons from Hipparcos trigonometric parallaxes can help us learn to deal with the isochrone age information. Simple approaches do not yield reliable results. More evolved statistical treatments may give good results, but requires *a priori* assumptions. Inverse methods can be more appropriate, like the ones applied to stellar population analyses in Local Group galaxies.

Painful as it may be given the amount of effort invested in gathering the data, we may have to accept that in some case, little reliable information can be obtained from the isochrone age data, although it 'looks good enough', just as the community came to accept that trigonometric parallaxes for individual stars with $\sigma_\pi/\pi >\sim 15\%$ could not be used in practice because of the infinite amplitude of the Lutz-Kelker bias, except for confrontation with well-defined, parametrised models (cepheid PL relation, RR Lyrae distance scale, cluster distances).

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