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uvby-β Photometry of Very Metal-poor Stars

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Abstract
Four-color and $H\beta$ photometry is used to study nearly 500 very metal-poor (VMP) stars from the BPS survey. The dereddened photometry is plotted in the c_0,$(b-y)_0$ diagram to derive photometric classifications of these VMP stars, with the classes ranging from horizontal branch to subluminous, and from the blue HB to red giants. Kinematic results for these VMP stars are compared to that of previously observed high-velocity (HV) and metal-poor stars. The *uvby*-β photometry is also compared to isochrones and to the globular cluster M92 to obtain conclusions concerning the relative and absolute ages of these extreme stars.

1.1 Introduction

Since October 1992, during seventeen observing runs, 497 VMP stars have been observed in the *uvby*-β photometric system using the H. L. Johnson 1.5m telescope and the six-channel *uvby*-β photometer at the San Pedro Mártir Observatory, Baja California, México, or using similar photometers or the DFOSC at the Danish 1.5m telescope at ESO, La Silla, Chile; with the DFOSC only *uvby* photometry was made but to a faintness of about V=15.5 magnitude. Observing and reduction techniques are described in papers by Schuster & Nissen (1988), and Schuster et al. (1996, 2004a). The newest photometric data and their errors will be presented in the latter publication.

1.2 Results

The c_0,$(b-y)_0$ diagram has been employed to classify the VMP stars into 11 categories (TO, MS, SG, RG, BS-TO, BS, RHB-AGB, HB, BHB, SL-BHB, and SL). The *uvby* photometry has been dereddened using our intrinsic-color calibration (Schuster & Nissen 1989) and our Hβ values, when available, or using a modified version of the Schlegel et al. (1998) reddening values. Our classification scheme in the c_0,$(b-y)_0$ diagram and the resulting classifications of the VMP stars will be documented in the following paper (Schuster et al. 2004a), as well as the calibration of the photometric absolute magnitudes and the sources of our kinematic data. The halo stars of our VMP and HV samples have been separated from the "high-velocity disk" stars using the methods developed in Schuster, Parrao, & Contreras-Martínez (1993).

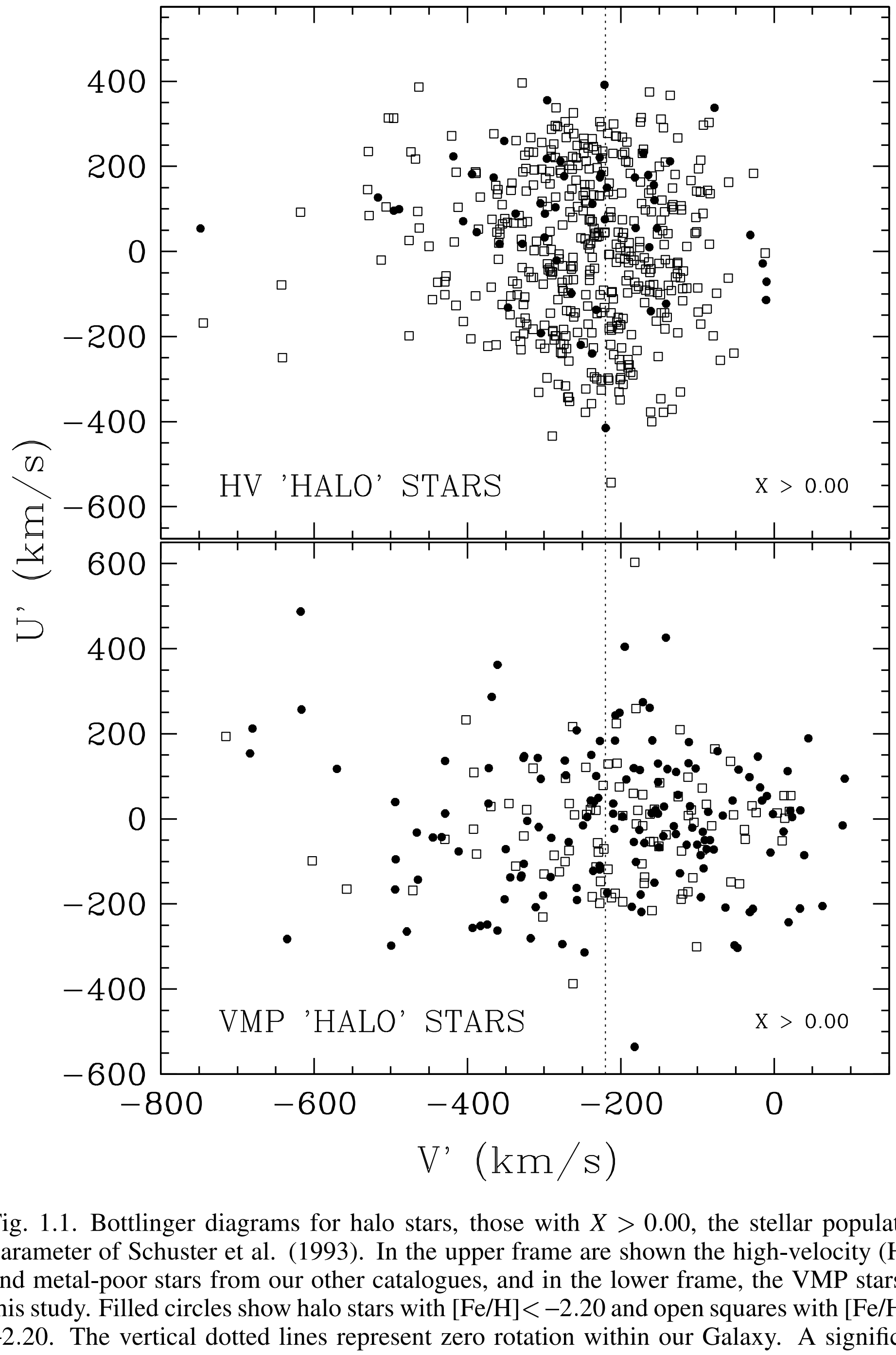

Fig. 1.1. Bottlinger diagrams for halo stars, those with $X > 0.00$, the stellar population parameter of Schuster et al. (1993). In the upper frame are shown the high-velocity (HV) and metal-poor stars from our other catalogues, and in the lower frame, the VMP stars of this study. Filled circles show halo stars with [Fe/H]< -2.20 and open squares with [Fe/H]$>$ -2.20. The vertical dotted lines represent zero rotation within our Galaxy. A significant difference in the Strömberg drifts between the two groups is seen, and both show significant negative tails in V'.

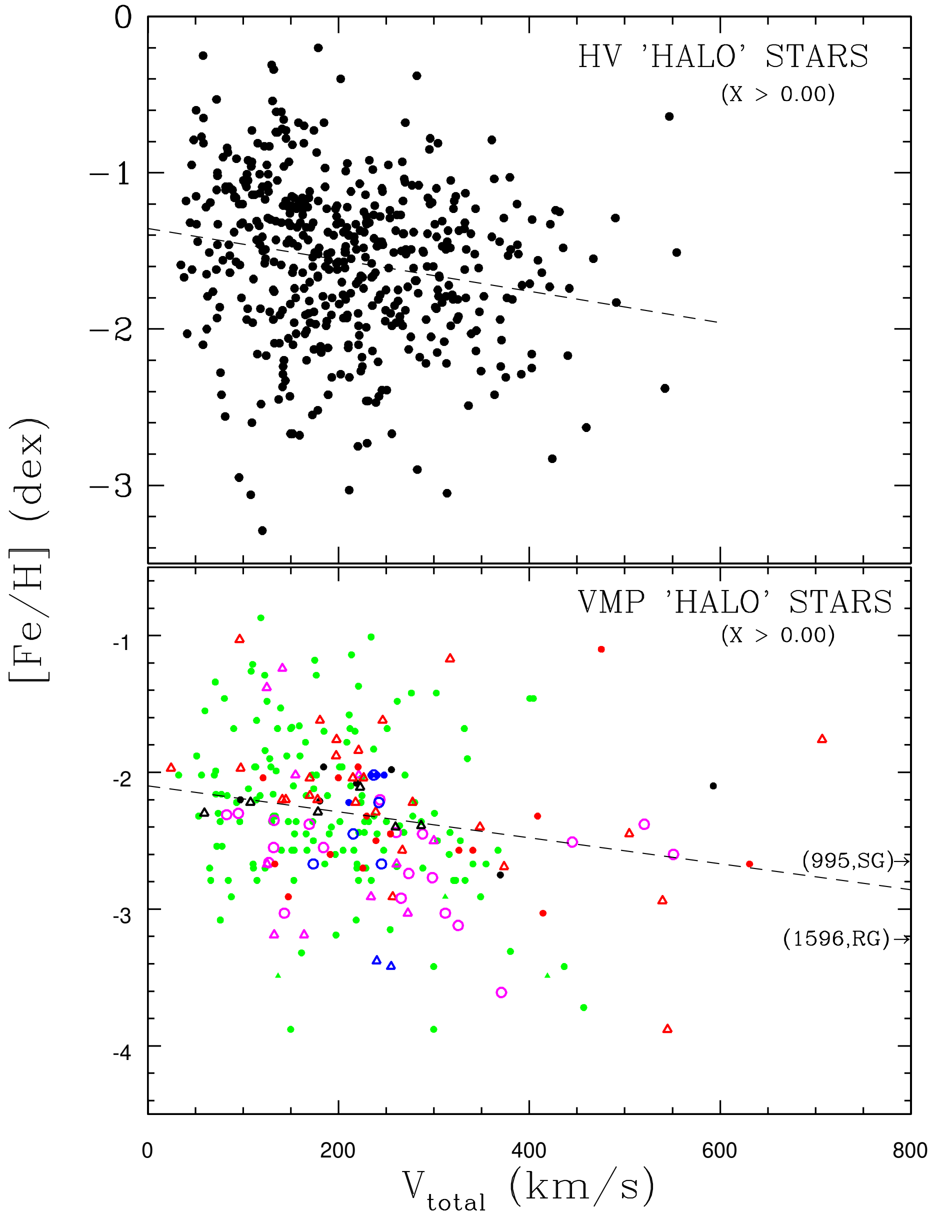

Fig. 1.2. [Fe/H] vs V_{total} diagrams for halo stars, those with $X > 0.00$, the stellar population parameter of Schuster et al. (1993). The V_{total} is the total velocity of a star with respect to the center of the Galaxy. In the upper frame are shown the high-velocity (HV) and metal-poor stars from our other catalogues, and in the lower frame, the VMP stars of this study. Color codes are used to indicate different photometric classifications: solid green circles for TO stars, solid black circles for the MS, open red triangles for subgiants, open magenta circles for red giants, open black triangles for the RHB-AGB, solid red circles for the HB, and so forth. The dotted lines show the results of simple linear unweighted regressions to the data; both have slopes of about -0.0010 dex/ km s^{-1}

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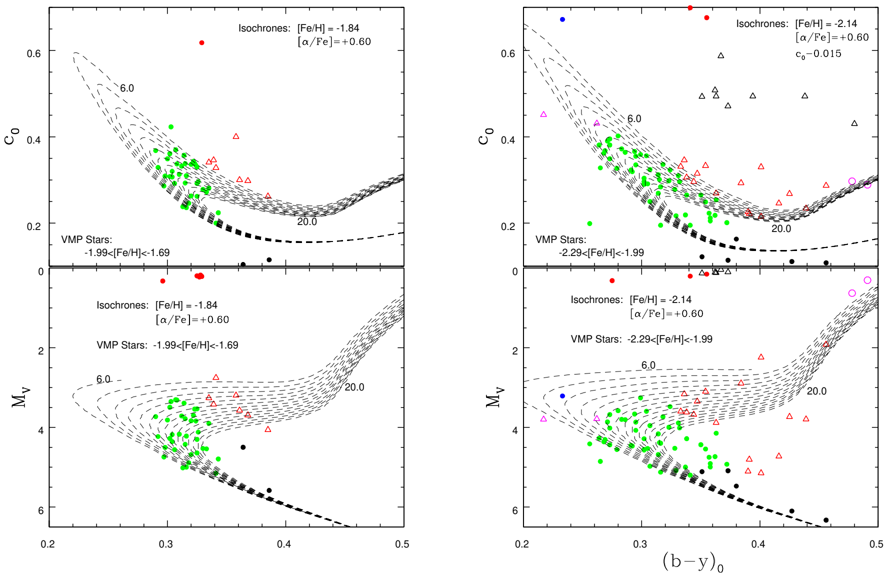

Fig. 1.3. c_0,$(b-y)_0$ and M_v,$(b-y)_0$ diagrams showing on the left VMP stars with -1.99 <[Fe/H]< -1.69 and isochrones for [Fe/H]= -1.84 and [α/Fe]=+0.60, and on the right VMP stars with -2.29 <[Fe/H]< -1.99 and isochrones with [Fe/H]= -2.14 and [α/Fe]=+0.60. The isochrones are those of Bergbusch & VandenBerg (2001) transformed to the observed plane using the color-T_{eff} relations derived by Clem et al. (2004). Our M_v values have been derived from a new calibration that makes use of Hipparcos stars with parallax errors of 10% or less (Schuster et al. 2004b). The c_0,$(b-y)_0$ isochrones on the right have been shifted downward by 0.015 magnitude to obtain a better fit with the observed points of the TO stars. The scatter and "very old" stars in the redder part of the these diagrams might be due to nitrogen variations via the effect of the NH band at 3360 Å on the c_0 index.

1.3 Conclusions

1. The VMP sample contains a wide range of stellar types, from horizontal branch (HB) stars to subluminous (SL), and from red giants (RG) to blue horizontal branch (BHB), with turn-off (TO), main sequence (MS), subgiant (SG), and blue straggler (BS) stars in between. 2. The mean (median) [Fe/H] value for our VMP "halo" stars is –2.31 (–2.32), while for our HV "halo" stars the mean (median) is –1.57 (–1.51), a difference of about 0.8 dex. 3. There is a significant difference in the mean Strömberg drifts between our VMP "halo" and HV "halo" samples. Surprisingly this drift for the VMP "halo" stars is less negative by about 40 km s^{-1}, more difference than is usually attributed to the V' velocities because of contrasting kinematic biases. The VMP "halo" sample has a mean (median) drift value of –214 (–193) km s^{-1}, while the HV "halo" a mean (median) of –249 (–239) km s^{-1}. 4. A possible radial gradient in the metallicities of Galactic halo stars has been detected, as seen in the [Fe/H],V_{total} diagrams, with lower mean metallicities at the higher kinetic energies, a slope of about –0.0010 dex/ km s^{-1}. 5. The youngest VMP stars have ages of about 10-11 Gyrs, and are probably 1-2 Gyrs younger than the globular cluster M92.

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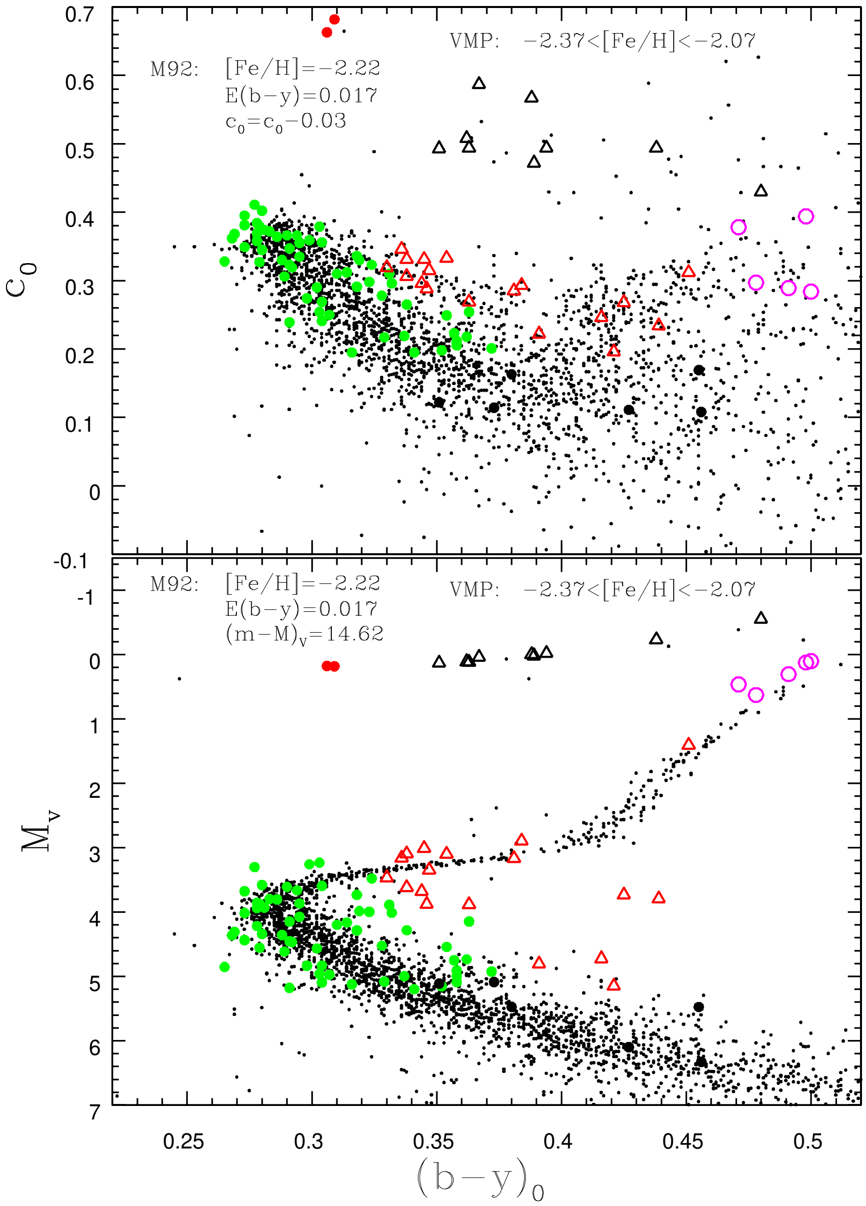

Fig. 1.4. A comparison of the VMP stars with the globular cluster M92 in the c_0,$(b-y)_0$ and M_v,$(b-y)_0$ diagrams. The data for M92 has been provided from the work of Grundahl (2000) and from Grundahl et al. (2000) and has been dereddened using the value E($b-y$)=0.017, with a distance modulus of $(m-M)_v$ = 14.62, and shifted downward in c_0 by 0.03 as discussed in the latter publication. Our M_vs as above. The youngest VMP stars appear slightly younger than M92, perhaps 1-2 Gyr younger.