ABUNDANCES AND AGES OF DISK CLUSTERS

Robert D. McClure and Bruce A. Twarog

Yale University Observatory

Larson has emphasized at this meeting that one relation which is valuable in determining the correct model for the formation of the Galactic disk is the dependence of stellar abundances on the time of formation of the disk stars. While Mayor has demonstrated that correlations exist between metal abundance and both kinematics and positions of stars in the disk, Larson has suggested that it is possible in an extreme infall model to have such trends and still have no age dependence.

The direct determination of ages of stars is a very difficult problem. For field stars the only practical way of estimating ages is by examining the positions of evolved F and G stars above the main sequence relative to theoretical isochrones. This method is error prone because the ages are very sensitive to the absolute magnitudes for which one must rely on trigonometric parallaxes that are of limited accuracy. In this paper we attempt to investigate the dependence of abundance using disk population clusters which, while having the disadvantage of being few in number, have two important advantages. First, the ages can be very reliably determined from the color-magnitude diagrams of the clusters. Second, the abundances can be accurately determined since they are the end product of observations of numerous stars in each cluster.

The ages of the disk clusters were estimated using the same procedure as described in Demarque and McClure (1977) using isochrones constructed by Ciardullo and Demarque (1977). The uncertainty in the fitting is small, and results in errors in the ages of about 10%. Since the Hyades sequence fits the isochrones for a helium abundance of Y = 0.30, all clusters were fitted to isochrones of this helium abundance but with metal abundances appropriate for each cluster. We should point out that we have tested all the clusters and found that assuming a helium abundance different from the Hyades for any given cluster makes little or no difference in the age determination.

The ultraviolet excess was obtained for stars in each cluster

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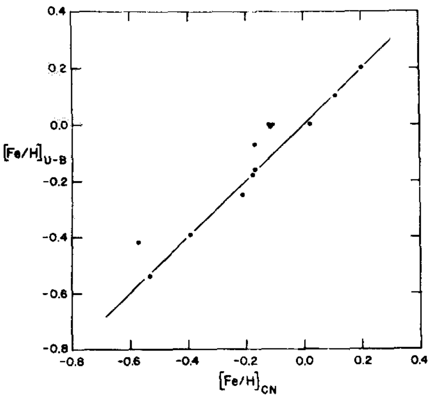

Fig. 1. $[Fe/H]_{UB}$ vs. $[Fe/H]_{CN}$ from Table 1.

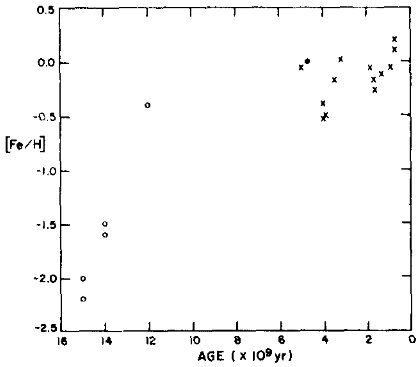

Fig. 2. [Fe/H] vs. Age from Table 1.

after appropriate reddening corrections were applied, and these were converted to equivalent iron abundances using the correlations [Fe/H] with δ (U-B) from Eggen (1964), Branch and Alexander (1973), and Wallerstein and Helfer (1966). We limited our sample of clusters to those for which both UBV and DDO photometry were available. The latter not only provided a second abundance measurement, but also ensured a cluster sample which had reasonably good color-magnitude diagrams. The cyanogen band strengths of giants from the DDO photometry were converted to an equivalent [Fe/H] by using the relation of Janes (1975). The [Fe/H] values from both methods were adjusted by a zero point correction to give [Fe/H] = 0.20 for the Hyades cluster. The above parameters and ages for each cluster are listed in Table 1.

Figure 1 shows the correlation between [Fe/H] values determined from ultraviolet excess and from cyanogen band strength. The correlation is surprisingly good, with the scatter being easily explained by observational errors. This one to one correlation points up the fact shown by Hesser et al. (1976), and discussed in this meeting by Castellani, that although the CN strengths vary widely among giant stars within globular clusters, the CN strengths for disk clusters are well behaved.

We have taken a mean of the [Fe/H] values for each cluster in Table 1 and plotted the abundance versus cluster age as seen in Fig. 2. Included are the values (open circles) for the globular clusters M92, M15, M13, and 47 Tuc from Demarque and McClure (1977). Examination of Figure 2 reveals two important results. First, the ages of the disk clusters are less than half the age of the globular clusters. King (1968) has pointed out on statistical grounds that it is unlikely that NGC 188 is as old as the oldest disk stars. To attempt an answer to this important question of the age of NGC 188 relative to the age of the disk we

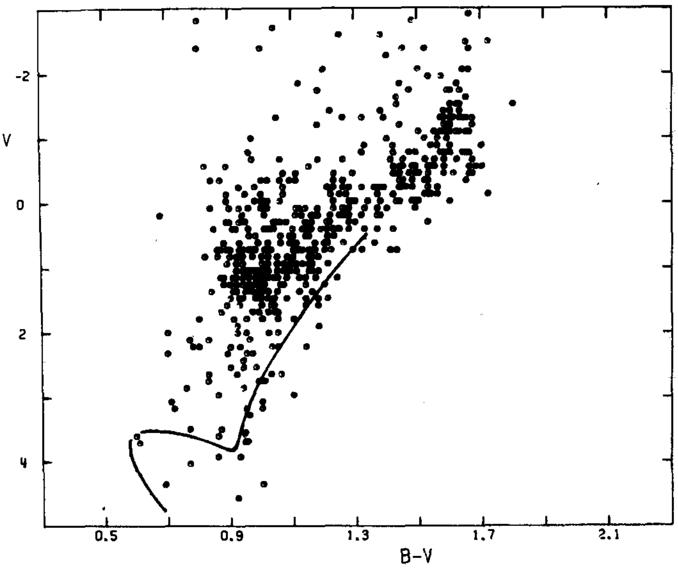

Fig. 3. Nearby Field Stars From Wilson (1976) Relative to NGC 188

refer the reader to the work of Wilson (1976) on absolute magnitudes of K giants from the width of the K-line emission reversal. Wilson points out that the oldest cluster giant branch forms a lower envelope in the HR diagram to the nearby field stars. We show a diagram illustrating this result in Figure 3, where the data have been corrected to a Hyades distance modulus of 3.30 (Hanson 1975, and Anthony-Twarog and Demarque 1977). The curve represents the principal sequence of NGC 188 as obtained from the data of McClure and Twarog (1977). If the NGC 188 helium abundance were lower than the Hyades abundance (see Twarog 1978) the NGC 188 sequence would be pushed upwards in Fig. 3 by about 0.30 mag, but the conclusions would be essentially unchanged. We point out that if significant numbers of stars of NGC 118 (essentially solar) age have comparable metal (solar) abundances, we would expect far more stars to lie below the NGC 188 giant branch due to errors in the magnitude estimates which amount to ∿ 0.30 mag for bright giants and which are even larger for the subgiants (see Wilson 1976). We do not, of course, rule out that there are disk stars older than NGC 188 and, indeed, the Geneva group has suggested at this meeting that such field stars exist. We think, however, that Fig. 3 indicates that star formation in the disk did not build to a peak at least until the epoch of formation of NGC 188.

Second, there appears to be no significant trend of abundance with time for disk clusters. We must emphasize that the old clusters tend to be both above the Galactic plane by up to 1 kpc and up to several kpc

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distant in the direction of the Galactic anticenter. Both these positions tend to produce metal poor clusters if the results presented elsewhere in this meeting are correct. If corrections for these effects were to be made for the clusters in Fig. 3, any possible trend of metal abundance with age would definitely be erased for the disk clusters.

We close by emphasizing the importance of determining not only if the metal abundance of disk stars has increased with epoch of formation, but also what proportion of disk stars are older than NGC 188. This research was supported by grant AST 76-22672 from the National Science Foundation.

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Table 1. AGES AND ABUNDANCE PARAMETERS FOR DISK CLUSTERS

Cluster	Age ($\times 10^9$ yr)	δU-B	δCN	[Fe/H]$_{U-B}$	[Fe/H]$_{CN}$
Hyades	0.7	$0^m.00$	$0^m.07$	0.20	0.20
NGC 2477	0.7	0.02	0.05	0.10	0.11
NGC 5822	0.9	0.03	0.00	0.00	-0.12
NGC 2360	1.3	0.04	-0.01	-0.07	-0.17
NGC 7789	1.6	0.08	-0.02	-0.25	-0.21
NGC 752	1.7	0.05	-0.01	-0.18	-0.18
NGC 3680	1.8	0.03	0.00	0.00	-0.12
M67	3.2	0.03	0.03	0.00	0.02
NGC 6819	3.5	0.06	-0.01	-0.16	-0.17
NGC 2243	3.9	0.11	-0.10	-0.42	-0.57
NGC 2506	4.0	0.13	-0.09	-0.54	-0.53
NGC 2420	4.0	0.10	-0.06	-0.39	-0.39
NGC 188	5.0	0.03	0.00	0.00	-0.12

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