MEASUREMENTS OF ABUNDANCES AND AGES OF OLD DISK CLUSTERS

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The old disk clusters represent a striking contrast to the globular clusters which will be discussed extensively at this meeting in that the disk clusters show few anomalies. This makes a discussion of their abundance measurements of particular interest at this meeting, and may shed some light on the cause of the peculiar behavior of the halo objects. It is also appropriate to discuss the ages of the clusters since the HR diagram is a major tool for obtaining the ages of stars. A complete sequence of stars of one age in a cluster can be fitted to the ZAMS of theoretical models, and accurate abundances averaged over numerous stars in the cluster can be estimated. We will discuss the ages and abundances of 11 disk clusters for which UBV and DDO photometry are available in the literature. This limits the sample to those for which good color-magnitude (C-M) diagrams exist. In addition we present the C-M diagrams of two clusters that we have studied and that are not yet published elsewhere. We will use these clusters to illustrate our procedures.

NGC 5822 is an intermediate age cluster whose C-M diagram is shown in Fig. 1. We have done iris photometry from 8 plates in each color, and believe that the scatter present near the main sequence is due to binary stars. Notice that the blue edge of the main sequence is well defined.

The color-color diagram for NGC 5822 is shown in Fig. 2 for stars near the principal sequences in the C-M diagram. Crosses represent stars slightly above the main sequence which could be binaries. The reddening, determined from DDO photometry in NGC 5822 and calibrations of Janes (1977a, b), is $E(B-V) = 0^{m}.12$ for giants, which is equivalent to $0^{m}.13$ for main sequence stars (see Hartwick and McClure 1972). After dereddening along appropriate

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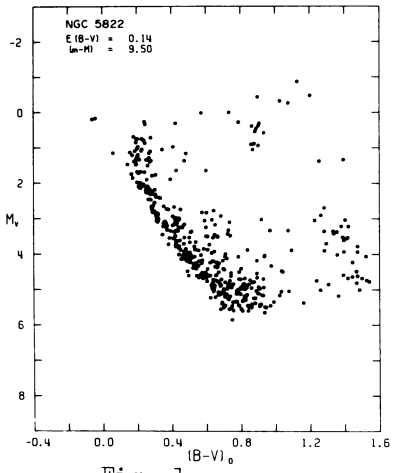

Fig. 1

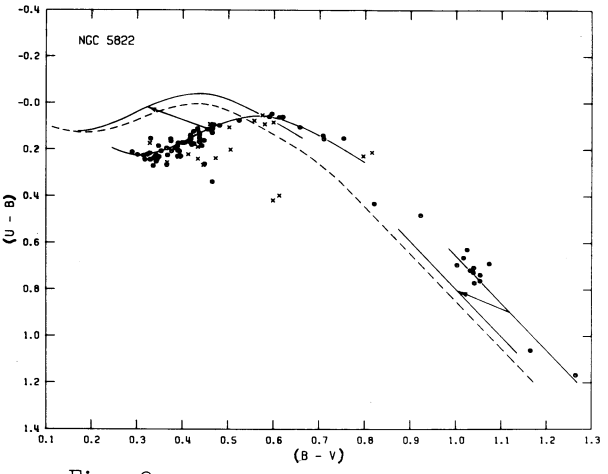

Fig. 2

trajectories (see Crawford and Mandwewala 1976), both giants and dwarfs show an ultraviolet excess of $\delta(U-B) \sim 0^{m}.05$ with respect to the Hyades sequences (indicated by the dashed curve).

The C-M diagram for NGC 2506 is shown in Fig. 3. We have superimposed a set of isochrones constructed by Ciardullo and Demarque (1977) and converted by them to the observational plane as described by Ciardullo and Demarque (1978). The Hyades main sequence fits models for Z =0.03, Y =0.30, and distance modulus $3^{m}.30$ (Hanson 1975, Anthony-Twarog and Demarque 1977). The distance modulus for NGC 2506 results, then, from fitting to the theoretical isochrones. The resulting ages for all the open clusters fitted in this way have almost no dependence on helium abundance.

The resultant data for clusters in our sample is shown in Table I. Values of [Fe/H] were obtained by consulting the $\delta(U-B)$ calibrations of Wallerstein (1962), Eggen (1964), Wallerstein and Helfer (1966) and Alexander (1973) and calibrations of CN strength by Janes (1975). For NGC 2243 a UV excess measurement, made by Norris and Hawarden (1977) from DDO photometry, has been averaged with the (U-B) abundance determination. Zero points of [Fe/H] were adjusted to give + 0.2 for the Hyades. The correlation of [Fe/H] values determined by the two methods is shown in Fig. 4, a correlation which is surprisingly tight. A similar correlation for globular clusters would be impossible because of the large fluctuations in CN strengths among stars of a given cluster. The contrast between halo and disk clusters has been pointed out by Hesser et al. (1976). Examination of their Fig. 1 shows large variations in CN strengths for metal-rich globular clusters such as 47 Tuc. Their Fig. 2, on the other hand, shows no scatter (other than observational) among stars in disk clusters, even for clusters like NGC 2420 which appears to be similar in metal abundance to 47 Tuc. (Demarque and McClure 1977).

Metal abundances are plotted versus age for these clusters from

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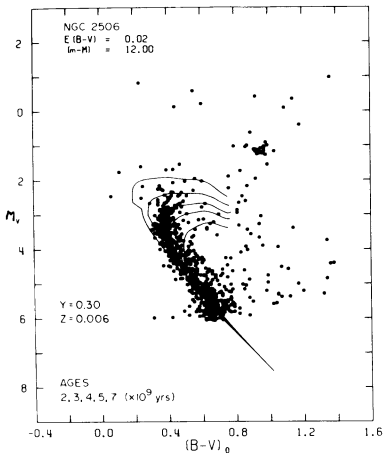

Fig. 3

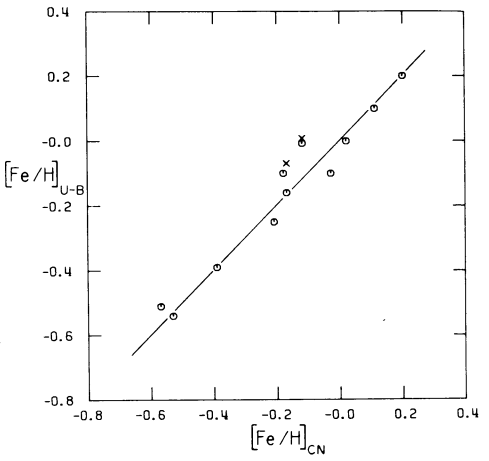

Fig. 4

similar data elsewhere by McClure and Twarog (1977). Differences from their data are small (new observations have been included here for NGC 5822 and NGC 2243).

As suggested by McClure and Twarog (1977) there appears to be no evidence for a variation of abundance with age for disk objects in the last 5-billion years. Rather, the most obvious trend is that between abundance and galactocentric distance (see Janes 1977b). The old galactic clusters which show a significant metal deficiency (NGC 2243, NGC 2420 and NGC 2506) are located 2-4 kpc in the anti-center direction. This trend of decreasing metal abundance with galactocentric distances has been discussed more fully by Janes (1977b) for a much larger sample of clusters. Another result is that at a given age there appears to be a significant spread in metal abundance of about $\pm$ 0.3 dex. It is necessary to conclude that material in the disk has not been well mixed.

TABLE I

Cluster	Age(yr)	δ(U-B)	δ CN	$[Fe/H]_{U-B}$	$[Fe/H]_{CN}$
Hyades	0.7×10^9	$0^m.00$	0.07	0.20	0.20
NGC 2477	0.7	0.02	0.05	0.10	0.11
NGC 5822	1.0	0.05	0.02	-0.10	-0.03
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	-0.10	-0.18
NGC 3680	1.8	0.03	0.00	0.00	-0.12
M 67	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	-0.51	-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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DISCUSSION

KRAFT: Do these three clusters share the low helium which you found in NGC 2420?

McCLURE: I can't say anything about NGC 2243, but NGC 2506 is almost identical to NGC 2420.

NORRIS: One might argue that the difference in CN properties between the open and globular clusters supports a primordial origin of the abundance anomalies in the latter. The globular clusters, being more massive, may be able to produce a second generation of stars possessing anomalies, while in the open clusters the ejecta from the first generation of supernovae may escape from the system.

SCHWARZSCHILD: Your concluding slide seems to me a beautiful contribution to the basic question of whether age or position in the Galaxy is the key factor determining the heavy element abundance of stars. Originally age was considered the main factor. More recently this one-sided view has been shown to be very incomplete. Now your conclusion indicates that for the last 5 billion yrs. position in the Galaxy is the dominant

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