PART III

THE CHEMICAL PROPERTIES OF THE DISC AND THE HALO IN OUR GALAXY

CHEMICAL PROPERTIES AND AGE OF THE COMPONENTS OF THE GALACTIC HALO

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1. INTRODUCTION

What we call Population II is composed by the stars populating the halo of our Galaxy, for which one finds evidences for an underabundance in the heavy elements and/or for an evolutionary age as large as (roughly) 10^{10} years. Similar star populations are at present recognized in the halo of other spyral galaxies, in elliptical galaxies as well as in smaller systems, such as the Magellanic Clouds and the so-called Dwarf Galaxies as the ones in Draco and in Ursa Minor. Then Population II looks like representing a very general constituent of present Universe.

When talking about the chemical composition of Population II stars one is facing the peculiar problem of the archeology of these stars: if we believe - as many people do - that the Universe came out from a big-bang, from the evidence that Population II represents the oldest population of stars in our Galaxy, one could expect stars originally composed by a mixture of hydrogen and helium, with negligible metals. This is not the case, as no star in our Galaxy is believed to have a metallicity lower than $Z \sim 10^{-4}$ (i.e. roughly 1% of $Z_\odot$), much more than expected on the basis of big-bang nucleosynthesis. Furthermore, Population II is far from being a homogeneous population, as clearly indicated by the large differences in the observed HR diagrams of galactic globular clusters ; as a matter of fact, differences in metallicity among Population II objects can be as large as a factor 10^2 , i.e. several order of magnitudes larger than in all the following star generations. So the investigation of the chemical composition of our halo population is essentially related to three, more or less connected, problems:

i) Where have been manifactured the heavy elements we find in the oldest

stars observed in our Galaxy?
ii) How the large spread in metal abundances has been produced?
iii) Where is the boundary (if any) between Population II and the earlier star population?

There is, I believe, an increasing agreement on the fact that something could be revised in the "classical" picture of the early hystory of our Galaxy, where Pop. II is the direct result of star formation within a collapsing protocloud of primeval matter. If the collapse of the protohalo took place in a time comparable to the hydrodinamic time scale, Hartquist and Cameron (1977) find, e.g., not easy to understand how there could be time during the collapse to form a first generation of hydrogen-helium stars, to let these evolve to the supernova stage,to mix the supernova ejecta into the remaining gas and then to form a second generation of stars which would still retain the kinematic properties of Pop. II stars. So these A.s suggest the occurrence of a pre-galactic population of massive stars, though other more or less exotic possibilities cannot be excluded "a priori". In this frame one expects that a detailed knowledge of the chemical evolution of the Population II will represent the key for understanding the early evolutionary hystory of our Galaxy. This subject is, of course, so wide and with so many connections, that it cannot be covered with any attempt to completeness. In the following I will attempt to summarize:i) what is directly known from observations, ii) what can be inferred from evolutionary theories and iii) what can be done in the near future. So we shall review the properties of both high velocity and globular cluster stars, though one has to bear in mind that we have no definitive proofs on the homogeneity for such populations, since we have only a lot of analogies as well as some possible discrepancies.

2. POPULATION II PHOTOSPHERIC ABUNDANCES

Curve-of-growth analysis of absorption lines in star spectra is,of course the more direct approach to the present composition of Population II star photospheres. The exceedingly large distances of many Population II objects early suggested the (successful) use of low dispersion spectra or multifilter photometry in order to obtain indirect informations on photospheric abundances. Among the more popular, one can remember the broad band index δ (U-B) (Sturch 1966), the intermediate band DDO photometry (Mc Clure and Van den Bergh 1968) and the so-called Preston's parameter (Preston 1959, Butler and Kraft 1975) based on the analysis of low dispersion spectra (see Bell 1975, Spinrad 1975 for more detailed discussion). On this basis we have a fairly large set of informations on the atmospheric abundances in both high velocity and globular clusters stars.

The first question is that of the helium abundance, which is of special interest in connection with the diffuse belief that most of present helium ($Y \sim 0.25 + 0.30$) has been synthetized in a hot big-bang. Helium abundance can be evaluated from the He I singlet/triplet ratio in hot stars, namely in the blue Horizontal Branch (HBB) stars occurring in some globular clusters as well as among field stars. By 1956 a sufficient number of HBB stars had been sudied to demonstrate a clear underabundance of He by a factor 10 or more (see Greenstein 1966). Though special variant cosmologies can account for a low production of helium during the big-bang (see, e.g. the recent work by Carr 1977), Greenstein, Truran and Cameron (1967) suggested that gravitational inward diffusion could deplete the original He from the atmosphere of HBB stars, which do not show any appreciable rotation and which are also expected to be stable against convection. More recently Greenstein and Sargent (1974) gave a convincingly evidence for the occurrence, among the high velocity population, of HBB and subdwarfs B (SDB) with a clear helium underabundance, toghether with the He-rich subdwarfs O. As suggested by Faulkner (1972), HBB,SDB and SDO halo stars are likely to be regarded as the remnants of Pop. II Red Giants which have undergone the He-flash suffering a different amount of mass loss. In this context, it is tempting to explain (Greenstein and Sargent 1974) the abrupt appearence of He in the atmosphere of halo SDO as the result of a mixing which breaks down the atmospheric stratification in such stars which are expected to have lost practically all the hydrogen envelope surrounding the evolutionary He core. As a whole, the best we can say is that we have <u>no</u> reliable spectroscopic informations on the original helium abundance in Pop. II stars, since abundance peculiarities related to stellar evolution likely affect the atmospheres of hot Pop. II stars, whereas in cooler stars, where mixing by convection is acting, helium lines cannot be observed.

As far as the heavier elements are concerned, all the observations agree in indicating roughly $-2.2 \lesssim [\mathrm{Fe/H}] \lesssim 0.0$ as the appropriate range for Population II objects.The Draco dwarf galaxy (something like a peri-galactic super-globular cluster) is believed to show a peculiar underabundance reaching $[\mathrm{Fe/H}] \sim -2.8$ (Canterna 1975). The highest abundances are recognized in metal rich globular clusters, like M 71 or NGC 6352, which have been classified as Pop. II objects essentially on the basis of the evidence for a red H.B. phase (see Arp 1955); at present we known that increasing the metal abundance, H.B.s are expected to merge in the R.G. branch (Cannon 1970), so that the quoted clusters do not show in this respect a real discontinuity with the so called old-disk clusters like NGC 188. DDO photometry by Hesser, Hartwick and Mc Clure (1977) indicates for both clusters a solar [Fe/H] value; different determinations of [Fe/ H] in globular clusters (Table 1) show to be in a fair agreement, confirming that clusters like M 71 look as bridging the gap in metal between Pop. II and Pop. I objects. As a general rule, metallicity of globular clusters looks decreasing with increasing distance from the galactic centre (Woltjer 1975).

Detailed abundance determinations of extremely weak-lined stars of Population II do not show clear systematic discrepancies with the "standard" (solar) abundance distribution of heavy elements, i.e. we do not get, till present, clear evidence for a time modification of the nucleosynthesis processes at the basis of the chemical evolution of the interstellar medium (see Pagel 1973). Nevertheless, spectroscopic and photometric surveys revealed a number of peculiarities in red giant spectra, mainly involving the abundance of CH and CN molecules. Peculiar CH and CN-strong stars have been found in a number of globular clusters, as well as among the field stars (see Hesser et al. 1977 for a list of references). At the same time peculiar weak-G-band stars (generally interpreted in terms of C-deficiency) have been found in M 92 by Zinn (1973), in NGC 6397 by Mallia (1975) and more recently in M 13 and M 15 by Norris and Zinn (1977). The calibration of DDO photometry in terms of cyanogen band strengths allowed Hesser et al. (1977) to perform a survey of 17 globular clusters, showing convincingly that CN strength indices of giant stars can vary, within a given globular cluster, much more than in Population I field or cluster stars.

It is generally suspected that such peculiarities are produced by abundance peculiarities related to stellar evolution, via the mixing of material from the nuclear burning regions to star surface, though in so

TABLE 1-
[Fe/H] values for galactic globular clusters and from different systems (Hesser et al. 1977)

Cluster	DDO	S	Canterna (1975)
M 92	- 2.2	- 2.18	- 2.2
M 3	- 1.5	- 1.57	- 1.4
M 2	- 1.0	- 1.01	......
47 Tuc	- 0.4	......	......
M 71	0.0	- 0.04	- 0.3
NGC 6352	0.0	......	......

me special cases(ω Cen) explanations based on successive generation of stars have been suggested (Freeman and Rodgers 1975). Results by Norris and Zinn (1977) on weak-G-band stars support the idea that G - band weakness is not accompanied by abnormalities in heavy element abundance (Ca,Fe) and that such anomalies are likely to be related to mixing processes rather than to primordial abundance variations, though the theoretical understanding is not yet completely satisfactory. One expects anyway that mixing from the H-burning processed regions acts in the sense of depleting C (and O) in favour of N. Mixing of carbon from the deep interior as a result of the core helium flash has been recently suggested by Auer and Demarque (1976) to explain the observed variations in the Balmer jump in some blue H.B. stars of M 92; such an occurrence would arise serious theoretical problems as far as the expected H.B. location of heavily C-enriched stars is concerned (see Castellani and Tornambè, 1977).

Substantial differences in the primeval C/O ratio for halo stars , when compared with disk stars, cannot be anyway ruled out (Zinn 1973a,b). As pointed out by Hesser et al. (1977) such an occurrence might push the C/O ratio in Pop. II stars near the critical value of unity, where the highly non linear growth of CNO band strength might amplify small differences in star parameters. Whatever their origin could be, the large spread in CN strengths observed in Pop. II stars looks as indicating a systematic difference between Pop. II and Pop. I stars even for similar metallicity.

3. EVOLUTIONARY THEORIES

For "normal" stars (i.e. neglecting close binary systems, peculiar rotations,etc) evolution is expected to be a function of star mass (M), age (t) and original chemical composition (Y,Z_i). Evolutionary theories and computations reached in last years a fairly high degree of accuracy so that at present we can reasonably expect to have a sufficient knowledge of star evolution,at least for a large portion of star lifetime.Population II systems represent an exceptionally good test for evolutionary theories, since the large occurrence of stars gives large evidences for later (relatively rapid) evolutionary phases, which, in turn, sensitively depend on the assumptions on the quoted evolutionary parameters.

As is well known, the observed HR diagrams of Pop. II clusters can be interpreted, with fairly good accuracy, in terms of isocrone loci only depending on the cluster age and the cluster chemical composition.In

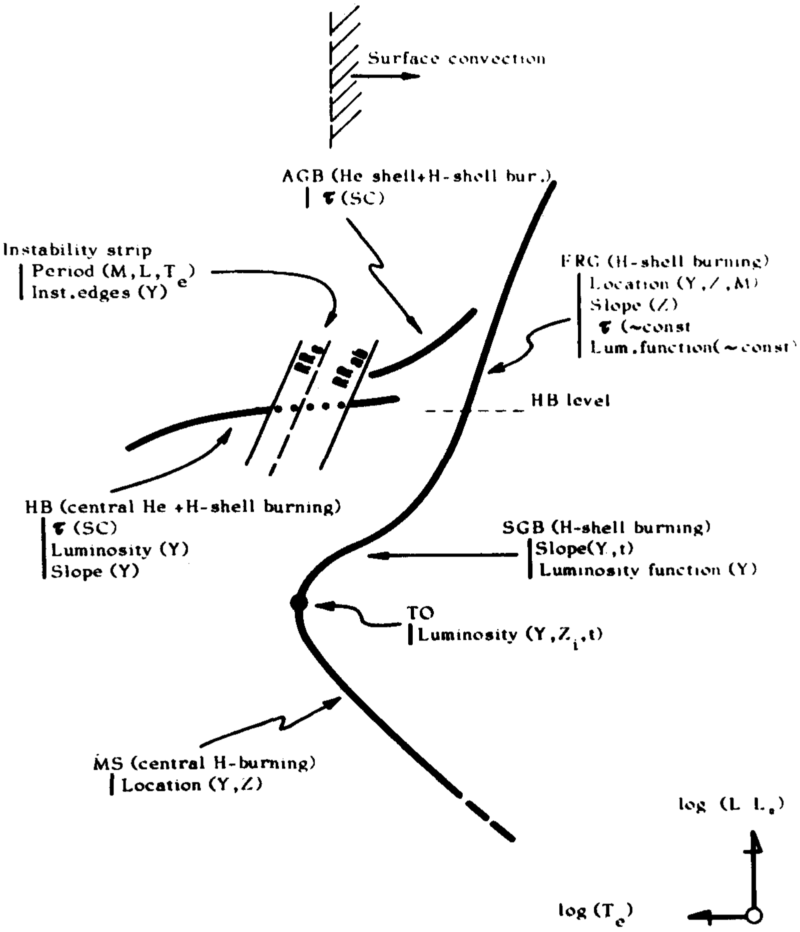

Fig.1 _ The locus in the H.R. diagram of the main evolutionary phases observed in globular clusters.Some observational data to be fitted with theory are reported; the evolutionary parameters on which the observed features mainly depend are given in brackets. τ represents star lifetime .

a reasonable situation we ought to ask the theory for the determination of one (unobservable) parameter, namely the cluster age. It is worthwhile noticing that, if this were the case, the present status of evolutionary theories would be able to give cluster ages with a really high degree of accuracy. Unfortunately, we know from the previous sections how many indeterminations on the chemical composition we have. Thus,we must try to extract from the observed HR diagram informations on the age,the helium content and, perhaps, on the relative abundance of CNO elements. One may say we are forced to try interpretation knowing no much more than nothing. Nevertheless, at the present time, theoretical constraints give a quite large set of informations (perhaps not yet largely acknowledged).

The point is that no evolutionary phase observed in globular clusters is unable, at least in principle, to give informations on the evolutionary parameters. In the following I will try to summarize the main connections between the theoretical frame and the cluster parameters.Referring to Figure 1, one has:

a) Main Sequence (MS).

The MS location depends on the chemical parameter Y and Z $(= \sum Z_i)$. Minor theoretical indeterminacies are connected with the theoretical treatment of the external convection (Castellani and Renzini 1968); no real dependence on the relative abundance of CNO elements is expected,as CNO burning is not efficient in such Pop. II low mass stars. From theoretical computations one derives (Caputo 1977) at log $T_e = 3.760$

$$\Delta M_{bol} = 2.84\,\Delta Y - 1.13\,\Delta \log(Z+0.001)$$

The accurate determination of the MS location in globular clusters is biased by the indetermination on the cluster distance modulus. Accurate photometry of MS stars in the cluster M 15 (Sandage and Katem 1977) gives a MS width due almost entirely to the known errors of measurement, putting some upper limits for chemical disomogeneity within this cluster.

Very metal-poor MS field stars, with available trigonometric parallaxes, look as being underluminous by about $\Delta m \sim 0^{m}.5$ as shown in Figure 2 (data from Hearnshaw 1976, Mould and Hyland 1976), i.e., roughly a half than expected on the basis of their Z-deficiency. Thus,a lower helium content cannot be excluded.

b) Turn-off point (TO) and Subgiant Branch (SGB).

The luminosity of TO point is a well known function of cluster age and chemical composition, dependent on the relative abundance of CNO elements but rather insensitive to variations in the assumed mixing len

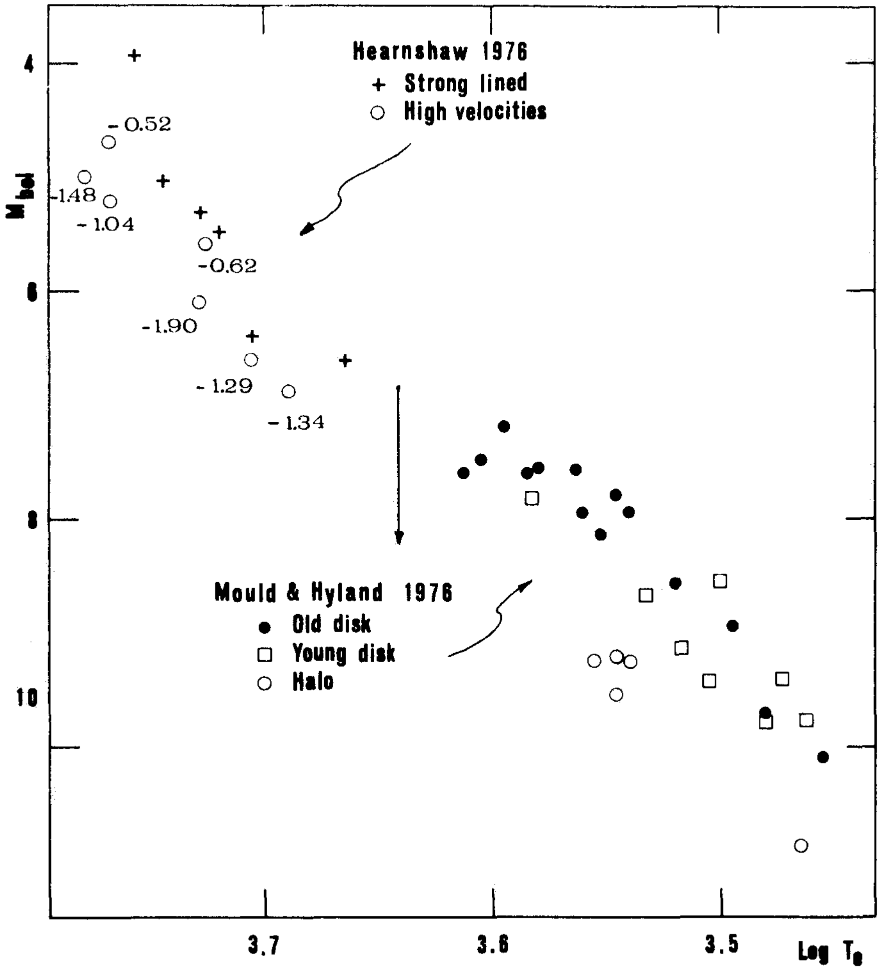

Fig.2 _ The locus in the H.R. diagram of metal deficient subdwarfs compared with the location of old disk and metal rich stars. The figures report some [Fe/H] values, as given by Hearnshaw (1976).

The arrow represent the shift in luminosity expected on theoretical basis when [Fe/H] = -2.0 .

gth (Simoda and Iben 1970).This is a particular case of a quite general rule:indeterminations in the treatment of external convection affect noticeably the effective temperatures but only slightly star luminosities. Apparent magnitudes of TO are known for a small number of galactic globular clusters.

The slope of SGB is steeper for greater age and larger helium content, nearly independently of the metal content. The luminosity is a more conspicuous function of Y.

c) First Red Giant Branch (FRG)

The location in the HR diagram of the FRG branch is a function of the evolutionary parameters (see Caputo et al. 1974 for a detailed discussion); the slope of the branch is a well known metal indicator. Renzini (1977) suggested such indicator might be rather insensitive to CNO abundances. Theoretical (Iben and Rood 1970) and observational (Cohen 1976) evidences support the possible occurrence of a consistent mass loss during the FRG phase. The mass M_c of the helium core at the end of FRG evolution (i.e. at the He-flash) is largely independent of the age of the cluster.

d) Horizontal Branch (HB) and Asymptotical Branch (AGB)

The occurrence of a differential mass loss is expected to scatter the initial locations of HB stars along the so called Zero Age Horizontal Branch (ZAHB),(see Rood 1972). ZAHB loci are roughly independent of the age and very sensitive to the original helium content. The star distribution along the ZAHB (i.e. "red" or "blue" Horizontal Branches) is also depending on the age and/or the amount of mass loss.

Further evolution of HB models is depending wether or not the so-called "induced semiconvection" (SC) is acting (Castellani et al. 1971). The observed lifetimes of AGB stars convincingly support such an occurrence (Castellani 1976) so that hereinafter the full efficiency of the induced semiconvection will be assumed.

The occurrence during HB evolution of a phase of pulsational instability (RR Lyrae variables) adds an independent set of relations, connecting the observed periods to evolutionary star parameters.

4. EVOLUTIONARY INTERPRETATIONS

The various connections among the different points of theory cannot be discussed here, owing to the formally complicate set of relations to be assembled (see,e.g., Caputo and Castellani 1975a).

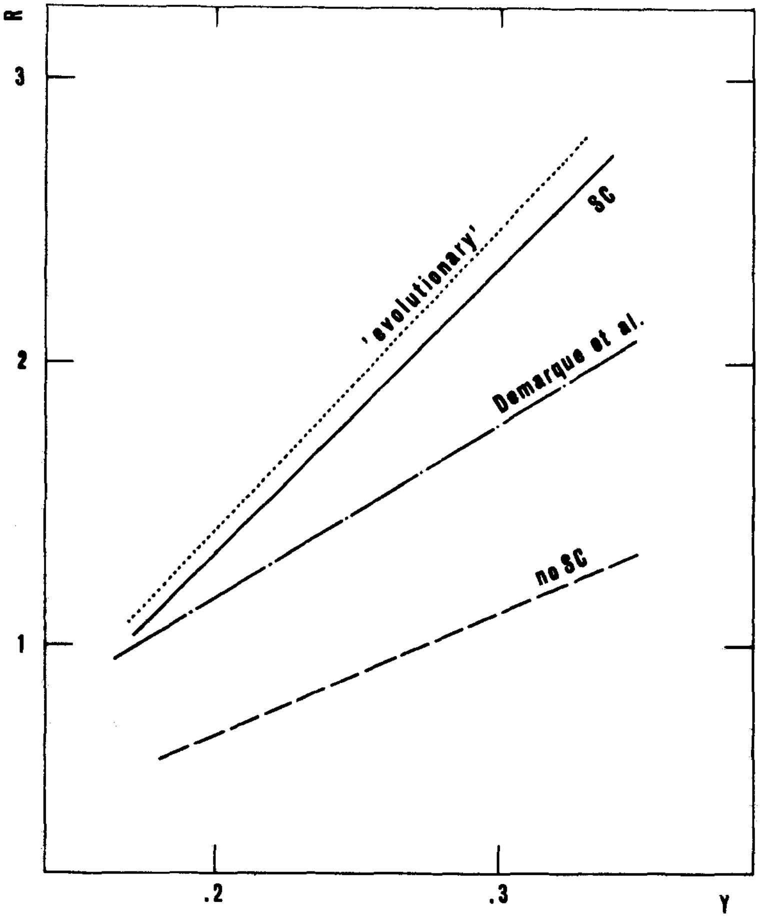

Fig.3 _ Theoretical calibrations of the parameter $R=n_{HB}/n_{FRG}$ (see text). From the bottom to the top one has: i) the calibration by Iben (see Iben 1974) where semiconvection (SC) is not taken into account; ii) the calibration by Demarque et al (1972b) where the influence of SC was estimated; iii) a recent calibration based on the computations by Wood (1975) where SC has been followed in details during the whole HB phase.
The dotted line at the top of figure as in case iii) but with a correction including the effect of increasing surface helium during FRG phases as given by Sweigart (1977).

Different ways can be used for overtaking many observational indeterminations and the lacking of complete informations. As a general rule, the relative differences (between two evolutionary phases or between two clusters) are more reliable than "absolute" characteristics, since "differential" characteristics are less susceptible to the ambiguity in the theoretical frame as well as to the observational indetermination. As a consequence, we can more easy detect (and try to explain) differences between the clusters, rather than the absolute value of the evolutionary parameters. It is true, of course, that many times one is dealing with "indications" rather than with real proofs, though the convergence of a set of such indications can be used to improve the reliability of the results.

The main results we are dealing with can be summarized as follows:
a) Large scale differences among galactic globular clusters (like HB colours) are well explained by the only variation of the observed metallicity Z. More detailed analysis shows that another evolutionary parameter must vary independently to account for the lacking of a full correlation of the observed HR diagrams with Z (Hartwick 1968, Castellani et al. 1970).

b) In the peculiar case of the cluster NGC 7006, the observational evidence (Hartwick and Mc Clure 1972) supported by theoretical investigations (Castellani and Tornambè 1977) suggest that such a "second parameter" could be the Z_{CNO}/Z ratio. (Note that, unfortunately, a large scatter in the values of this parameter throughout, at least, the H-burning shell could be an alternative explication for the peculiar wide Horizontal Branches (as in M 3 and M 5), which are generally interpreted through a spread in the star masses or in the masses of the helium core (Demarque et al. 1972)).

c) The number ratio R of HB stars to FRG stars more luminous than the HB level has been suggested as a powerful indicator of the original Helium content (see Iben 1974). The theoretical calibration of this parameter followed the increasing knowledge of HB evolution, as shown in Figure 3. At present, it is difficult to escape the conclusion that in most globular clusters $Y \sim 0.22 \div 0.25$. A similar conclusion seems to arise from the observed slope of SGB in M 92 and M 3 (Simoda and Fukuoka 1976) as well as from the properties of RR Lyrae pulsators in Oosterhoff type I clusters (Wood et al. 1977) and in Oosterhoff type II clusters (Caputo et al. 1977).

d) The reality of, at least, small fluctuations in Y ($\Delta Y \sim 0.02$) seems supported by the observed properties of RR Lyrae pulsators (Caputo and Castellani 1975b). It is interesting to notice that a peculiar high helium abundance has been suggested for the cluster M 13 on quite independent basis by Caputo and Castellani (1975) and by Simoda and Fukuoka (1976). Variations in the evolutionary ages have been also suggested by Caputo and Castellani (1975c).

Finally one has to notice that the failure of CM diagrams of metal rich globular clusters to superpose with those of old disk clusters like NGC 188, in despite of the similar metallicity, has been interpreted (see Hesser et al.1977) as a further evidence for the existence of some still unidentified overall difference between Population II and Population I clusters.

5. CONCLUSIONS

What I believe to be a firm point, is that the evolutionary theory at present rejects the low "spectroscopic" helium, as well as the diffuse prejudice of an "everywhere-constant" helium $Y \sim 0.30$ (see also Spinrad 1975). It is not clear if there exists a general correlation between Z and Y, as the one proposed by Peimbert and Torres-Peimbert (1974) : available observations suggest that R (and then Y) is increasing with Z (Castellani and Martini 1977), though such a result could be largely biased by selection effects in the observations. What we need for firmer conclusions on the whole argument are more and more accurate and statistically significant observations.

In this context, the general agreement between evolutionary and pulsational theories for Population II gives severe constraints on the evolutionary parameters of well observed RR Lyrae-rich clusters.

The knowledge of a few more TO luminosities would be a crucial test for important suggestions, and the same holds, e.g., for the relation between observed periods and colours of RR Lyrae variables (see Caputo and Castellani 1975a). A systematic survey of the spectra of globular cluster stars is urgently needed (Hesser et al. 1977), as well as a more clear insight on the characteristics of the field-halo population.

Accurate analyses of field RR Lyrae,as the one given by Lub (1977), looks as being very promising. The Y-dependent relation between the surface gravity and the effective temperature in HB stars found by Gross (1973) and substantially confirmed by Caloi et al. (1977) could allow for other independent informations on the original helium,when and if the doubts raised by Hearnshaw (1976) on spectroscopic gravities in metal poor stars will be clarified.

Finally, I wish to raise a few questions on Population II objects in the neighbourhood of our Galaxy, in the feeling that such a problematic is closely related to the evolutionary hystory of our Galaxy:
i) What kind of variation in the evolutionary parameter produced the observed strong difference between the HR diagrams of the Dwarf Galaxies in Draco and in Ursa Minor?
ii) Why globular clusters membering the Dwarf Galaxy in Fornax show different colours?
iii) What about the evolutionary status of globular clusters in the Magellanic Clouds?
This is only a sample of the open questions which promise to give in the near future informations on the chemical hystory of this local portion of the Universe.

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