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Is the Universe younger than the Galaxy? The lesson of the Globular Clusters

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Abstract. For a long time the Globular Clusters populating the halo of the Milky Way was considered too old with respect the age predicted by the widely accepted model of the Universe. Now, a solution of this longstanding problems appears on the horizon

1. Introduction.

In the last couple of decades the most widely used cosmological models have been based on the assumptions that the Universe is flat (i.e. the average density is equal to the critical density or $\Omega = 1$) and the dominant constituent of the Universe was a not well identified kind of cold dark matter with just a few percent of normal baryonic matter. The cosmological constant, Einsteins biggest trouble, was usually ignored. Following this model, the resulting Universe is too young with respect to the oldest stars in the Milky Way, whose ages are derived by using stellar evolution theory. However, recent measurements of the cosmic microwave background coupled with the distance determinations obtained from high redshift supernova experiments seem to solve this longstanding problem. The fluctuations of the microwave background indicate that the Universe is flat (i.e. $\Omega \sim 1$), while the supernova distance scale implies the existence of a large cosmological constant, so that the amount of cold dark matter should be strongly reduced (down to 20-30% of the total density). This implies that the expansion rate was lower in the past and, in turn, the Universe is older than previously believed.

2. Globular Clusters turn off: the Age Indicator.

Since the pioneering papers (Sandage 1962) was immediately understood that Globular Clusters are among the oldest components of the Milky Way. Their ages may be derived by comparing the observed Color-Magnitude diagrams with theoretical isochrones. The location in the HR diagram of both the Main Sequence and the Red Giant Branch do not change with Age. On the contrary, the Turn Off and the Subgiant Branch are good age indicators. The Turn Off luminosity has been widely used to derive the absolute age of Globular Clusters. The turn off color also depends on age, but its use as age indicator is presently restricted due to the large uncertainties affecting the theoretical stellar temperatures and the color-temperature relation. Theoretical isochrones for GC stars firstly appeared at the beginning of the seventies (Iben 1971, Ciardullo & Demarque 1977). Owing to the improvement of our knowledge of the physics governing the behaviour of stellar matter (opacity, EOS, nuclear reaction rates and the like), the theoretical models of H-burning low mass stars have been recursively updated. Milestones were the paper by Vandenberg & Bell (1985), in which several inputs physics were revised, and the one by Straniero & Chieffi (1991), firstly including electrostatic corrections in the equation of state. This last result have been more recently confirmed by Chaboyer & Kim (1995), by using the more refined OPAL EOS. As a consequence of these improvements, an about 15% reduction of the predicted Globular Cluster ages have been found. At the end of the eighties and during the nineties it was progressively realized that the α-elements (O, Ne, Mg, Si, Ca, etc.) are overabundant, with respect to iron in Pop II stars. The effects on the age were deeply studied by Salaris, Chieffi, Straniero (1993) and substantially confirmed by Vandenberg et al. (1996). Another important improvement was the inclusion of microscopic diffusion. The timescale of microscopic diffusion is so long that it is generally neglected in stellar model computations. However, during the long lifetime of an H-burning low mass star, this phenomenon may slowly alter the chemical profile and, in turn, it may lead to a modification of the stellar structure. Globular Cluster isochrones including He diffusion were computed by Proffit & Vandenberg (1991) and Chaboyer et al. (1992). More recently Straniero, Chieffi & Limongi (1997, SCL97) and Castellani et al. (1997) have also included the diffusion of heavier elements. A further reduction of the estimated GC ages (about 10%) was found.

3. The present status of the art.

Homogeneous measurements of turn off luminosities have been listed by Rosenberg et al. (1999). We have obtained the ages of the 35 GCs of this database by means of the turn off luminosity/age relation presented in SCL97 (diffusion isochrones). Distance moduli have been derived by fitting the observed ZAHB listed in the same database with the theoretical ZAHB of SCL97. Metallicities and α-elements overabundances have been taken from Carretta & Gratton (1997). The bulk of the GCs is coeval (within a bona fide error of ± 1 Gyr), with interesting exceptions at large metallicity ([Fe/H]>1.2). Once the five Clusters whose age differs by more than 2 Gyr from that of M15 are excluded, an average age of 12.95 ± 0.65 Gyr is found. Note that the quoted error is just a standard deviation. Actually, systematic errors in the distance scale (as due to uncertainties in ZAHB models) could largely affect this average value.

4. Further progress: the onset of the CNO-burning.

During most of its life, a low mass star burns H in the center via the pp chain. However, when the central H mass fraction reduces down to 0.1, the nuclear energy realized by the H-burning becomes insufficient and the stellar core must contract to extract some energy from its gravitational field. Then, the central temperature (and the density) increases and the H-burning switches from the pp-chain to the more efficient CNO-burning. Thus, the escape from the MS is powered by the onset of the CNO-burning, whose bottleneck is the $^{14}N(p,\gamma)^{15}O$ reaction. A modification of the rate of this reaction alters the turn off luminosity, but leaves almost unchanged the stellar lifetime, which is mainly determined by the rate of the pp reaction. The minimum energy explored in nuclear physics laboratories is 200 KeV, well above the region of interest for the CNO-burning in astrophysical condition ($\sim 20 - 80$ KeV), so that the values used in stellar model computations are largely extrapolated. How reliable are the extrapolated values of this reaction rate? The complexity of the resonant structure of the ^{15}O compound nucleus makes unpredictable the extrapolation down to typical astrophysical energies. In particular the astrophysical factor for this reaction is strongly dependent on the interference with a subthreshold resonance (7271 keV). Such a big uncertainty demands a measurement of the astrophysical factor at energy as close as possible the typical Gamow peak in low mass turn off stars. LUNAII (Laboratory for Underground Nuclear Astrophysics), already working inside the Gran Sasso mountain (LNGS laboratory of Assergi, Italy), will rich these energies at the end of 2001.

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