The Age of the Oldest Stars from the Faint End Slope of the White Dwarf LF in Globular Clusters

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Scientific category:	STELLAR POPULATIONS
Instruments:	OPT/CAM, NIR/CAM
Days of observation:	18

Abstract

We propose to determine the absolute magnitude of the end of the white dwarf cooling sequence in the nearest globular clusters. Cooling models of white dwarfs predict ~ 1 mag difference between an age of 10 and 15 Gyr. The end of the disk cooling sequence is known to occur at $M_{bol} = +17$; in the nearest globular clusters, this would be at H=30-31, reachable in a 30 hour exposure. Since the faintest WD are both red and faint, the infrared imaging capability of NGST is ideal for this task. Diffracted light from relatively bright (20th mag) main sequence stars must be controlled. This experiment would be the first measurement of the ages of the oldest stars that is independent of the main sequence turnoff and stellar evolution theory.

Observing Summary:

Target	RA	Dec	K_{AB}	Configuration/mode	Days
NGC 6752	19 10	-59 58	32.0	NIR/CAM R10	6
NGC 104	00 24	-72 04	32.0	NIR/CAM R10	6
NGC 6397	17 40	-53 40	32.0	NIR/CAM R10	6
				Grand total days	18

■ Scientific Objectives

At the present time, the only secure method for measuring the ages of the oldest stars relies on fitting the main sequence turnoff point of the oldest globular clusters. Stellar ages derived from this approach fundamentally depend on the accuracy of stellar models used, and on the underlying physics of nucleosynthesis. While there is justifiable confidence that these are well understood problems, there remain significant uncertainties that prevent absolute age measurements from being much better than $\approx 25\%$ (Bolte & Hogan 1995). In addition, for the oldest, most metal poor stars (those considered most likely to be the first stellar generation and therefore of order the age of the Universe) there are uncertainties such as the importance of diffusion, which could decrease available hydrogen in the core and therefore reduce the ages. Since the 1950's when it was realized that stellar ages could be determined and constrain the age of the Universe, there have been times when the ages of the oldest stars seemed to exceed the derived expansion age of the Universe (most recently with early HST measurements of the Cepheid distance scale; Freedman et al. 1994). These instances virtually always reignite discussion of the possibility of a lambda cosmology, reflecting the folk wisdom that "you can't be older than your ma". For example, the standard cosmology adopted at a recent STScI meeting on the distance scale was $H_0 = 70 kms^{-1}Mpc^{-1}, \Omega = 1, \Lambda = 0$, which gives 9.5 Gyr for an expansion age. This conflicts even with recent low Hipparcos-based estimates for globular cluster ages (Gratton et al. 1997) not to mention more conventional approaches (Richer et al. 1996). Recently, the possibility of a lambda cosmology has received major impetus from the study of supernovae at cosmological distances (Garnavich et al. 1998) and preliminary attempts to combine those findings with fits of the cosmic background fluctuation spectrum. If indeed we are in a lambda cosmology, it then becomes *essential* to have as many independent constraints as possible on the ages of the oldest stars. The white dwarf cooling sequence offers a constraint on the ages of the oldest stars that is independent of hydrogen burning main sequence models. There are other physical uncertainties, such as the process of white dwarf cooling. However, the method offers an independent approach to age determination and also the possibility of age dating globular clusters relative the oldest stars in the disk. The WD cooling sequence method thus may settle a long standing question, whether there is an actual gap of a few Gyr between the oldest globular cluster stars and the oldest disk stars.

White dwarfs were first discovered in globular clusters using HST (Richer et al. 1995) and have been utilized to set precision distances to globular clusters (Renzini et al. 1996). Very deep HST imaging has been proposed to attempt to reach the end of the WD cooling sequence, but it appears well beyond the capability of HST to reach to such faint magnitudes (e.g. to $V \approx 31$) which was not achieved even in the Hubble Deep Field. In addition, measurement of the end of the cooling sequence by definition demands that photometry and completeness should be excellent at the claimed WD cooling sequence termination point. NGST would have two advantages. First, as a cooled infrared telescope of 8m aperture, NGST is projected to reach $m \approx 31$ in the near-IR bands, second, even optical backgrounds would be lower at L2, making an optical V, I campaign also a viable opticon. Considering the

case of 47 Tuc with modulus of 13.5, the termination point must lie brighter than $M_{bol} = +17$ or $H \approx 30.5$. This is comfortably above the detection limit for NGST, and there is much to be gained by imaging these cool stars in the near-IR.

To be successful, the WD cooling sequence method must be able to produce a luminosity function for old globular clusters of a quality comparable to that currently available for the disk (Liebert, Dahn, & Monet 1988, Oswalt et al. 1996). This is a challenging problem, because while the turnover is observed in the disk LF at $10^{-4}L_\odot$, one must at the minimum reach $10_\odot^{-4.5}$ to discriminate between ages of 10-15 Gyr. Even for the disk, much depends on the very small samples available for the coolest white dwarfs, and Leggett, Ruiz, & Bergeron (1998) find an age for the disk of 8 Gyr, significantly younger than Oswalt et al. 1996, yet very dependent on their sparsely populated faintest bin. Therefore, I emphasize that confident age discrimination demands measurement of the faint end slope for $< 10^{-4.5}L_\odot$ requiring very careful measurements of completeness, and a solid ($S/N > 10$) detection of objects classified to lie in the faintest bin of the LF (Oswalt et al. 1996 their Fig. 1).

No doubt, there are uncertainties that remain in the cooling theory, such as the onset of crystallization. However, Richer et al. have compared the bright end of WD LF in M4 against models (Wood 1995, Bergeron et al. 1995) and find that these uncertainties are not a problem. Further progress is likely, as there is great interest in the subject due to the possibility that white dwarfs may account for much of the Galactic halo dark matter (Alcock et al. 1996).

1 Requirements for the NGST architecture

The imaging of white dwarfs in globular clusters requires that it be possible to obtain photometry of faint stars in fields crowded by bright stars. Obviously the exact field must be chosen with great care, as globular cluster giants will be extremely bright in the infrared ($M_H \approx 9$). The difficulty of measuring the faint WD against a sea of main sequence stars 5-10 mag brighter is another problem, and may require the use of wide-field apodization to suppress the overlapping diffracted profiles of the main sequence stars. Overlapping diffraction spikes can produce a background that overwhelms the WD or produces spurious detections.

There is a further requirement that relative astrometry can be performed on frames taken 6 months to a year apart. The aim is to separate cluster members from the background/foreground contaminants.

Alcock, C., Allsman, R.A., Axelrod, T.S. et al. 1996, ApJ, 461, 84.

Bergeron, P., Wesemael, F., & Beauchamp, A. 1995, PASP, 107, 1047.

Bolte, M., & Hogan, C.J. 1995, Nat, 376, 399.

Freedman, W.L., Madore, B.F., Mould, J.R. et al. 1994, Nat, 371, 757.

Garnavich, P.M., Kirshner, R.P., Challis, P. et al. 1998 ApJ, 493, 53.

Gratton, R. Fusi Pecci, F., Caretta, E. et al. 1997, ApJ, 491, 749 .

King, I.R., Anderson, J., Cool, A.M., & Piotto, G. 1998, ApJ, 492, L37.

Leggett, S.K., Ruiz, M.T., & Bergeron, P. 1998, ApJ 497, 294.

Liebert, J., Dahn, C., & Monet, D. 1988 ApJ, 332, 891.

Oswalt, T.D., Smith, J.A., Wood, M.A., & Hintzen, P.A. 1996, Nat, 382, 692.

Renzini, A. Bragaglia, A. et al. 1996, ApJ, 465, L23 .

Richer, H. et al. 1995, ApJ 451, L17.

Richer, H. et al. 1996, ApJ 463, 602.

Richer, H. et al. 1997, ApJ 484, 741.

Wood, M.A. 1995 in White Dwarfs, ed. D. Kowester & K. Werner (Berline:Springer), 41.

∎ NGST Uniqueness/Relationship to Other Facilities

Measurement of the faint end slope of the WD cooling sequence will require senstivity just at the limit of NGST capabilities. No other existing or planned facility can do this observation in any reasonable integration time. For example, if an HDF-level investment of time on the Advanced Camera were to be used, it would be possible to just detect $V \approx 29$. However, we are required to measure WD fainter than $V = 30.5$ to obtain a secure measurement of the cooling sequence.

Richer et al. 1997 argue that HST with Advanced Camera might be able to observe white dwarfs at $M_V = 17.5 (V = 30)$ in the globular cluster M4. This would achieve constraints at the 12 Gyr level but would not be able to distinguish among older ages. A single cluster detection would be less useful than relative measurements across several clusters with different metallicities. Convincing arguments concerning age demand a clear demonstration that the LF differs from the local disk WD LF, again demanding faint magnitudes.

∎ Observing Strategy

Deep HST images of globular cluster fields for WD studies are targetted toward away from the clsuter core, to decrease crowding and scattered light from bright stars. The minimum field covered would be one WFPC2 field; a 4×4 arcmin field would be better. The 3 clusters chosen span fully the range in abundance commonly found in the Galactic globular clusters, $-2 < [\text{Fe/H}] < -0.5$. Further, 47 Tuc is a member of the "disk" system of globular clusters. These observations may also constrain whether the globular cluster system is coeval or if there is an age-metallicity relationship.

Cool (4000K) DA white dwarfs (hydrogen) have $V - I \approx 1.2$, $V - K \approx 1.5$ (Bergeron et al. 1995). Optical imaging may be desirable, as the color differences in the infrared are small – $(J - K) \approx 0.3$ mag – over a wide temperature range. On the other hand the coolest WD could still be separated from the faint main sequence and from the background stars by the IR colors and use of proper motions. Images should be obtained in Johnson I (or near 1 micron) and H or K, or alternatively in V and I. There is a need for a wide enough color baseline to distinguish the white dwarf cooling sequence from the background of foreground faint stars and background extragalactic objects.

2 images should be separated by at least 6 months in order that the proper motion of the cluster can be used as a further discriminant to separate the WD from the background population. The 2 sets of images can also be used to study completeness, which is critical to

the method. King et al. 1998 have shown that the proper motion of NGC 6397 is sufficient to clearly separate all cluster members from other objects, over just a year time difference between exposures.

◼ Special Requirements

Maximum FWHM:	20 mas at 1 μm
Minimum FOV:	2′ at 1 μm
RMS repointing accuracy:	100 mas

◼ Precursor/Supporting Observations

It would be desirable to measure complete WD luminosity functions in old Galactic open clusters (NGC 7789 and NGC 2158 for example) to test the cooling theory. Ground-based surveys to discover more faint WD in the local disk, and parallaxes for the newly discovered stars, will also aid in the ultimate interpretation of these results. Attempts will be made with Advanced Camera to work on this problem with HST.