Anchoring the Population II Distance Scale: Accurate Ages for Globular Clusters

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The metal-poor stars in the halo of the Milky Way galaxy were among the first objects formed in our Galaxy. These Population II stars are the oldest objects in the universe whose ages can be accurately determined. Age determinations for these stars allow us to set a firm lower limit to the age of the universe and to probe the early formation history of the Milky Way. The age of the universe determined from studies of Population II stars may be compared to the expansion age of the universe and used to constrain cosmological models. The largest uncertainty in estimates for the ages of stars in our halo is due to the uncertainty in the distance scale to Population II objects. We propose to obtain accurate parallaxes to a number of Population II objects (globular clusters and field stars in the halo) resulting in a significant improvement in the Population II distance scale and greatly reducing the uncertainty in the estimated ages of the oldest stars in our galaxy. At the present time, the oldest stars are estimated to be 12.8 Gyr old, with an uncertainty of $\sim$15%. The SIM observations obtained by this key project, combined with the supporting theoretical research and ground based observations outlined in this proposal will reduce the estimated uncertainty in the age estimates to 5%.

The expansion age of the universe is determined by the present expansion rate of the universe (given by the Hubble constant, H_0), the matter density of the universe (parameterized by Ω_M) and the vacuum energy density of the universe Ω_Λ. Astronomy is entering into an era of precision cosmology where these fundamental cosmological constants will soon be determined to an unprecedented accuracy from a variety of ground and space based observations. These SIM key project observations and resultant age determination for the universe will provide an important, independent check of the preferred cosmological model.

The ages we determine will also be used to probe the early formation history of the Milky Way. Understanding the process of galaxy formation is a key quest in astrophysics and is one of the long term goals of NASA's Origins Program. The Milky Way plays a unique role in furthering our understanding of galaxy formation as it is the only large galaxy for which we can obtain detailed chemical, kinematic, and chronology information. The Milky Way provides us with a fossil record of its formation period, which yields unique insights into the process of galaxy formation.

RR Lyrae variable stars are Population II standard candles and can be used to determine the distances to globular clusters and nearby galaxies beyond the reach of SIM. An important part of this key project will be to determine the luminosity of the RR Lyrae stars. This will be done via distance determinations to globular clusters rich in RR Lyrae stars and a selected sample of RR Lyrae stars in the field. This calibration of the luminosity of RR Lyrae stars will allow accurate distances to be obtained to a number of distant globular clusters and nearby galaxies (such as the Large and Small Magellanic Clouds). Refining the distance estimates to nearby galaxies will help calibrate the zero point of the extragalactic distance scale.

In order to achieve these goals, the following SIM observations will be obtained:

1. Parallax and proper motion measurements to 5 stars in each of 21 different globular clusters. These clusters have been chosen to span a range in metallicities, horizontal branch types, number of RR Lyrae stars and Oosterhoff type

2. Parallax measurements to a selected sample of 60 field RR Lyrae stars, chosen to complement the RR Lyrae star observations taken by FAME

3. Parallax and proper motion measurements to 60 metal-poor main sequence turn-off and subgiant branch stars in the field, allowing us to determine the age of the halo stars and directly compare this to the globular clusters ages.

Field stars make up about 99% of the halo, and are an important population to study in our quest to understand the early formation history of the Milky Way. The parallaxes we obtain for a large sample of main sequence turn-off and subgiant branch stars in the halo of the Milky Way will allow us to accurately determine the ages of these stars and will complement our globular cluster age estimates in providing a firm lower limit to the age of the universe.

To take full advantage of the SIM parallax results will require a concentrated effort to reduce other uncertainties associated with the age determination process. Accurate photometry and heavy element abundances will be obtained for all of the target stars and globular clusters. Helium abundances will be determined through studies of eclipsing binaries in the nearest globular clusters and double-lined spectroscopic binaries in the halo. We will also undertake detailed spectroscopic studies for stars in selected globular clusters to establish a very high quality set of gf values, and apply those results to determine the atmospheric parameters and [Fe/H] values for all of our program clusters and field stars. We will obtain the even more crucial abundances of oxygen and other elements for all of our targets. We will seek to reduce possible systematic errors by using a variety of oxygen lines in stars in selected clusters. The resultant high-precision chemical compositions will be used as input parameters to the stellar models and isochrones. The input physics used to construct the theoretical stellar models and isochrones will be improved through a continuing investigation of the fundamental physics which governs the evolution of stars. These ground based observations and theoretical work are key to substantially reducing the error in age estimates for the oldest stars in the Galaxy.

This investment will lead to an improved understanding of the galaxy formation process, a substantially improved Population II distance scale and an determination of the minimum age of the universe to an accuracy of 5%.

Figure 1: HST picture of a portion of the globular cluster 47 Tucanae (from R. Gilliland). This SIM key project will determine the parallax to this cluster to an accuracy of 2%, allowing the age to be determined with an accuracy of 6%.