Wide-Field Imaging from Space of Early-Type Galaxies and Their Globular Clusters

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Abstract

Wide-field imaging from space will reveal a wealth of information about the globular cluster systems of any galaxies in the local universe that are observed by such a mission. Individual globular clusters around galaxies in the local universe have compact sizes that are ideal for the excellent spatial resolution afforded by space-based imaging, while systems of these globular clusters have large spatial extent that can only be fully explored by wide-field imaging. One example of the science return from such a study is the determination of the major formation epoch(s) of galaxies from the ages of their globular clusters determined via their optical to near-infrared colors. A second example is determining the sites of metal-poor globular cluster formation from their cosmological bias, which constrains the formation of structures early in the universe.

1 Why JDEM Imaging of Globular Cluster Systems

Globular clusters are invaluable fossil records of the early formation history of the galaxy in which they are located. Composed of roughly one million stars that formed at the same time with similar composition and that have remained bound for up to a Hubble time, each globular cluster provides an observable record of the age, metallicity, and kinematics at the time it was formed. Because these quantities are determined for individual globulars, studies of globular cluster systems can constrain the distribution of the ages and metallicities rather than the global average of these key galaxy quantities revealed by most studies of the integrated light of galaxies. Globular clusters are also observed to form in major starbursting episodes in the local universe, so their properties provide a way to trace the major formation episodes in their host galaxies. Moreover, because typical globular clusters contain roughly one million stars, they are bright and can be readily observed as individual objects out to sufficient distances (∼ 15 Mpc) to obtain a significant sample of...
elliptical galaxies. This allows the investigation of the formation history of massive early-type galaxies that are absent in the Local Group, but make up the majority of stellar mass in the local universe (e.g. Hogg et al. 2002). Consequently, studies of globular cluster systems have long played an important role in constraining how and when the major formation episodes in galaxies occurred (e.g. Ashman & Zepf 1998, Harris 2001).

The study of extragalactic globular cluster systems has been revolutionized by space-based imaging with the Hubble Space Telescope. This is in large part because the size of extragalactic globular clusters is very well-matched to diffraction limited optical imaging with a 2-m class telescope. Specifically, a typical globular cluster half-light radius of several pc at a distance of 10 Mpc corresponds to \( \sim 0.05'' \) on the sky. However, in one critical aspect, the study of extragalactic globular cluster systems is not well suited to HST imaging. The systems of globular cluster systems around massive early-type galaxies extend into the halos of the galaxies, covering tens of arcminutes on the sky (e.g. Rhode & Zepf 2004 and references therein). Therefore, wide fields of view are required in order to accurately determine total properties of globular cluster systems around galaxies. Moreover, the outer halos of galaxies may hold unique clues to the assembly history of galaxies, and globular clusters are one of the few probes available in these regions. In this contribution, we highlight two key science questions that would be addressed by wide-field, space-based imaging of galaxies in the local universe and their globular cluster systems.

2 Constraints on the Formation Epoch(s) of Elliptical Galaxies

Globular cluster systems are key tools for determining the formation history of elliptical galaxies because the ages and metallicites of their globular clusters can potentially be determined, thereby yielding the major formation epoch(s) of the host galaxies. Studies in optical colors have revealed that globular cluster systems of elliptical galaxies often have color distributions with two or more peaks (e.g. Kundu & Whitmore 2001, Larsen et al. 2001). This is one of the clearest signs that elliptical galaxies form episodically, and is consistent with earlier predictions for elliptical galaxies formed by the mergers of disk galaxies (Ashman & Zepf 1992). While the optical colors of globular cluster systems indicate an episodic formation history, they do not significantly constrain \textit{when} these events occur. This is because optical colors alone can not generally distinguish between different age and metallicity combinations (the age-metallicity degeneracy). In some specific cases with strongly bimodal color distributions, the cluster systems must be mostly old and have a bimodal metallicity distribution to account for the red and blue populations (e.g. Zepf & Ashman 1993). However, a general understanding of the age and metallicity distribution of globular cluster systems requires the breaking of
the age-metallicity degeneracy.

The addition of near-infrared photometry to optical data provides a way to break the age-metallicity degeneracy (e.g. Puzia et al. 2002). The basis for this technique is that the flux of a simple stellar population in the near-infrared is primarily sensitive to metallicity, while optical fluxes have a greater sensitivity to age. This approach has resulted in the first identification of a substantial population of intermediate-age globular clusters in an ordinary elliptical galaxy (Puzia et al. 2002), and studies are now being carried out of larger samples of galaxies (e.g. Hempel et al. 2003). However, these studies are limited to the inner regions of galaxies because of the modest size of current near-infrared arrays and also, more fundamentally, because of the low surface density of globular clusters in the outer regions of galaxies. Specifically, even with careful image classification and multicolor selection, contamination of globular cluster samples in wide-field ground-based imaging is a concern (e.g. Rhode & Zepf 2001). As demonstrated by HST, imaging at 0.1" resolution effectively eliminates most of this concern by separating background galaxies, foreground stars, and globular clusters (e.g. Kundu et al. 1999).

Any JDEM observations of early-type galaxies in the local universe would provide optical and near-infrared luminosities of their globular clusters over a wide field with little contamination. This would then allow the use of the optical to near-infrared technique to determine the ages and metallicities of the major formation epoch(s) of these galaxies from the inner regions out into their halos. This would place important constraints on the formation history of elliptical galaxies, particularly in their outer regions for which there are few other constraints.

3 Cosmological Bias of Metal-Poor Globular Cluster Populations

The low metallicity and the “halo”-like extended spatial distribution of metal-poor globular cluster systems suggests that they generally formed at high redshift. These objects may therefore be the best available fossil records of structure formation at early epochs. One way to address the question of the formation sites of metal-poor globular clusters is to determine their “cosmological bias.” Specifically, galactic halos that are more massive and in denser environments will tend to have more of their mass collapsed by a given redshift than halos of lower mass and in poorer environments. Thus, a given formation redshift for metal-poor globular clusters translates directly into a specific prediction for the “biasing” of metal-poor clusters towards higher mass halos, with the adoption of a constant formation efficiency of globular clusters per collapsed halo mass. This can be further tested by comparison with the spatial distribution of the metal poor clusters, which is also dependent on formation
epoch and halo mass (see Rhode & Zepf 2004 and Santos 2003).

To determine the cosmological bias of the metal-poor globular clusters, their total number and spatial distribution around galaxies of different masses and environments are required. Current work along these lines has primarily utilized the ground-based CCD Mosaic cameras covering fields of roughly 30′ × 30′ (e.g. Rhode & Zepf 2004). These data are a significant improvement over those available earlier, and the field size covers most or all of the metal-poor globular cluster systems of a broad range of galaxies in the local universe. However, as discussed in the previous section, space-based imaging is invaluable for identifying globular clusters over these large fields. Therefore, JDEM imaging of galaxies in the local universe would provide high quality total numbers and spatial profiles of the metal-poor component of globular cluster systems for the determination of the biasing of this population. This would then constrain when and where these structures formed early in the universe.

I would like to thank my many collaborators on projects related to those described above, and acknowledge support from NASA Long-Term Space Astrophysics grant NAG 5-11319.

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