Future Opportunities for Globular Cluster Astronomy at Ground Based Facilities

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Abstract. In spite of great progress over the last ~ 10 years, especially thanks to HST, a number of exciting open problem still puzzle astronomers working on globular clusters in our own and other galaxies. These problems range from determining more accurate ages to assess whether massive black holes hide at the center of some clusters, from identifying the physical origin of red giant winds to assess whether there is an influence of cluster structure and dynamics on the evolution of individual cluster stars, from demonstrating whether or not some clusters possess a dark matter halo on their own to eventually understand the formation of globular clusters in the context of galaxy formation, and more. In this review, I briefly sketch how ground based telescopes and their instrumentation can help solving these problems through the present decade, 2001-2010. A glimpse to the next decade is also given.

1. Introduction

This conference demonstrates the wide, enduring scientific interest of globular clusters (GC) for a broad variety of astrophysical and cosmological issues. This is indeed a very active field of astronomical research, and as such it has a number of open problems, currently under investigation. In this context, I have been asked by the organizers to review the perspectives for such problems to be solved (or at least effectively attacked) in the near future using ground based facilities, with emphasis on 8-10m class telescopes. I will do so leaving implicit that space borne facilities will widely complement in several areas, suffice to mention here the enormous progress in GC research that has been achieved using HST and its instruments. I should also acknowledge that this review is going to be somewhat biased towards the ESO Very Large Telescope (VLT), because it is the ground based facility I am more familiar with. Finally, emphasis will especially be on the telescopes and instruments that will be available in the course of the present decade.

In the next Section a list of open problems in GC research is presented, while in the following Section 3 some of the tools that may solve them are briefly mentioned and commented.
2. What Are the Problems?

Globular clusters offer what is perhaps a unique variety of research opportunities. They are at once prototypical N-body systems for dynamical studies and prototypical simple stellar populations for both stellar evolution and population synthesis models. They are astronomical objects for which most accurate ages can be obtained and they are tracers of the potential well of their parent/host galaxies as well as of their early chemical evolution and mass assembly. Here are some of the hot topics in current GC research.

- **Globular Cluster Ages** remain one of the key issues in observational cosmology (as a proxy to the age of the universe) and can provide important clues on the formation and early evolution of the Milky Way galaxy and its satellites. Improvements in the accuracy of cluster age determinations depends on improving upon three main ingredients, namely:
  * Distances: most progress is expected to come from space observations combined with multiobject spectroscopy from the ground (coupling proper motions and radial velocities in the so-called quasi-geometric method). For some methods (e.g., main sequence fitting to local subdwarfs) next item will also help.
  * Composition: [Fe/H] and [$\alpha$/H] are required to derive accurate ages from the main sequence turnoff. The abundance of s- and r-process elements and composition anomalies can be investigated using the same data.
  * Theoretical Models: there is still room for improving and testing the stellar evolution clock used for age determinations, an activity for ground-based theorists which is not covered by this review.

- **Globular Cluster Dynamics** is another area of active observational and theoretical research. Progress in understanding the dynamical evolution of the clusters will be achieved by addressing issues such as:
  * Binaries: determining their frequency, radial distribution, etc., is of prime importance for understanding the dynamical evolution of the clusters.
  * Tidal Tails: mapping the ongoing evaporation and stripping of stars from the clusters.
  * Central Black Hole: do some cluster possess a central, massive BH? If so, did it form in a single event or from the merging of many stellar mass BHs?
  * Dark Matter: are (some) clusters embedded in a “dark matter” halo of their own? While certainly not primordial, some globular clusters may be the remnant of a bigger entity ...

- **Long Standing Puzzles** that still remain unresolved are quite numerous, for example:
  * Mass Loss on RGB & AGB: color-magnitude diagrams provide compelling evidence that GC stars lose $\sim 0.2 \ M_\odot$ during the RGB and additional $\sim 0.1 \ M_\odot$ during the AGB. Star to star variations in the total amount of mass that is lost are also required to account for the HB morphology. Yet, almost nothing is known about the physical mechanism responsible for the wind mass loss in red giants, other than it cannot be radiation pressure (on either molecules or dust).
HB Blue Tails, Gaps, Jumps, and Rotation still puzzle astronomers. We don’t know for sure the origin of any of these phenomena, and to which extent they are related to each other. For a long time it has been suspected that the cluster structure (density, dynamical history, etc.) may play a role in establishing at least some of these features. There is a potential link between cluster dynamics and the evolution of individual cluster stars, quite worth to be explored further.

Composition Anomalies affecting CNO and other light elements, whose origin is still debated (primordial? early accretion from AGB ejecta? deep mixing? in a combination thereof?).

Exotic Objects: there is plenty of them in GCs, including:

- LMXBs have been discovered in great numbers by X-ray satellites, and many still await for their optical identification and characterization.
- Binary Pulsars are especially frequent in GCs, and offer a unique opportunity to add information on the outcome of massive star supernova explosions, as well on the role of massive binaries on the dynamical evolution of the clusters.
- Cataclysmic Variables are also found (in quiescence) in relatively large numbers in deep HST images, and most of them await for further monitoring and spectroscopic study.

Globular Cluster Systems in external galaxies is an area where progress has been extremely fast in recent years. Besides being interesting objects on their own, these GCs are used to map the potential well of the parent galaxies, and are even more interesting as fossil relics that may shed light on the formation and early evolution of their host galaxies. Ground based observations can greatly help to attack these problems, namely determining their

- Ages & Metallicities from colors and integrated spectra, also relative to the field population of the host, and their
- Dynamics within the galaxy potential well, probing the dark matter distribution at large distances, and reveling the degree of their orbital anisotropy and angular momentum.

Globular Cluster Formation remains as perhaps the ultimate, still unsolved problem in GC research.

- Why in the Very Early Universe CGs formed so numerous? If this was prompted by galaxy merging, does this imply that most of the merging leading the assembly of galactic spheroids took place at high redshift, say z ≳ 3, with just sporadic such events later on?
- Why the Metallicity Distribution of the GCs is prominent at low metallicities, contrary to that of the stars in the host spheroid?
- Why Bimodality in the GC metallicity distribution is prominent in some galaxies and absent in others?
- Why the Disks of most spiral galaxies appear to be and have been sterile for GC formation? [Galactic GCs are clearly part of the spheroid, nothing to do with the disk, either thin of thick, with the metal rich ones belonging to the Galactic bulge.] What are the masses, ages, and metallicities of the few bright clusters occasionally found in disks?
Why Instead LMC, a flattened dwarf irregular, is so actively forming \( \sim 10^5 \, M_\odot \) GCs?

Why the average metallicity of the GC populations is systematically lower than the average metallicity of the spheroids to which they belong?

3. What Are the Tools?

Having listed the problems, now comes a list of tools on optical/infrared ground based telescopes that can help solving them.

- **Optical/IR Wide Field Imagers** (\( \sim 1/4 - 2^\circ \) field of view) such as e.g., CFHT/Megacam, VST/\( \Omega \)Cam, UKIRT/WFCAM, VISTA. One can expect these facilities to be extensively used for:
  - *Star Selection and Astrometry* for multiobject spectrographs (see below).
  - *Mapping Tidal Tails* in Galactic globulars.
  - GCs in External Galaxies, their identification, astrometry and multicolor photometry.

- **Low- & Medium-Resolution** (\( R = 200 - 3000 \)) high multiplex (MPX) Spectrographs, e.g., GEMINI/GMOS, Keck/DEIMOS, VLT/VIMOS, etc. will offer a great variety of opportunities for GC research, including:
  - *Star Membership* in GCs via radial velocity selection, especially useful for GCs projected over very crowded stellar fields, such as the GCs belonging to the Galactic bulge.
  - *Composition Anomalies*, such as those of CH, CN, NH, and related anomalies, in both giants and dwarfs.
  - *Line Indices* for GCs in other galaxies (e.g., the Lick indices \( < \text{Fe} >, \text{Mg}_2, \text{H}_\beta \), etc.) will be of prime importance to better characterize GC families, compared to colors alone. Systematic differences or similarities among the various GC families and their correlations with the properties of the host galaxies could provide important clues on both galaxy and GC formation.

  For example, an instrument such as VIMOS at (\( R \approx 2000 \), MPX=200) will allow to observe thousands of objects/night down to mag \( \sim 22 \).

- **High-Resolution, High Multiplex Spectrographs** (\( R = 5000 - 40,000 \)), e.g., the VLT FLAMES feeding UVES (\( R = 47,000; \) MPX=8) & GIRAFFE (\( R = 7000 - 20,000; \) MPX=130) will begin a new era for stellar spectroscopy, in particular for GC stars. For example, such a facility will allow to obtain:
  - *Radial Velocities* (\( \pm \) few km/s) for thousands of mag \( \lesssim 20 \) stars/night, that will allow extensive membership assignment and census of binaries; again RVs with better accuracy (\( \lesssim 1 \) km/s) for thousands of mag \( \lesssim 18 \) stars/night, allowing distance determinations by the quasi-geometric method, in combination with proper motions with HST.
  - *Chemical Composition* (from S/N\( \sim 100 \) spectra) for hundreds of mag \( \sim 18 \) stars/night, allowing the abundance of many interesting elements to be determined, e.g., Li, C, N, O, Na, Mg, Al, Si, Ca, Fe, Sr, Ba, Eu, and perhaps even Th, and U.
The Future from the Ground

• *Hα* Emission and narrow circumstellar absorption lines for *dozens* of RGB/AGB stars/night with *R* ≃ 47,000, thus enabling the investigation of mass loss processes, and
• Rotational Velocities & composition anomalies for *dozens* of EHB stars/night.

• Integral Field (3D) Spectrographs, such as e.g., VIMOS/IFU, GIRAFFE/ARGUS, SINFONI, CIRPASS, etc. will allow unprecedented spectroscopic studies in GC cores, including:
  • Stellar Dynamics in cluster cores, e.g., checking for massive BHs, easily finding any very fast star that might be there,
  • Monitor Transients, such as cataclismics, LMXBs, etc.,
  • Discover Interesting Objects, e.g., very hard binaries, etc.

• Adaptive Optics (AO) assisted imaging and spectroscopy (e.g., Keck/AO; GEMINI/ALTAIR; VLT/NACO; SUBARU/AO; VLT/SINFONI) may not help much to reach deeper limiting magnitudes in sparsely populated fields, but certainly will add further opportunities in very crowded fields, such as GC cores and distant GCs. For example, AO will provide
  • Deep near-IR imaging and spectroscopy of stars within ∼ 20″ from cluster center,
  • Deep near-IR imaging of clusters in M31.

• High-resolution near-IR spectroscopy, with e.g., CRIRES at the VLT, *R* = 100,000 (with AO), ∼ 22,000 (without AO) will open up new opportunities for spectroscopic studies of GC stars, for example:
  • Chemical Composition from near-IR lines and bands, complementing optical spectroscopy.
  • Obscured Clusters in the Galactic bulge may become accessible to high resolution spectroscopy of cluster members.

• 50-100m Telescopes (e.g. OWL) 1 mas resolution, limiting magnitude ∼ 35, may well allow to:
  • Map the Evolution of GC Systems up to *z* = 5 and beyond, and finally
  • See Globular Clusters in Formation, all the way to *z* = 5 and beyond!

4. Conclusions

Given the capabilities of the ground based 8–10m class telescopes and of their instrumentation it is quite easy to anticipate where major progress in GC research is going to happen in the present decade (2001-2010).

I believe that we are about to witness a quantum jump in multiobject spectroscopy of GC stars, at low, intermediate, and high spectral resolution. There will be the capability to observe thousands and thousands of stars, and the impact on GC studies will perhaps be similar to what were for imaging the CCDs in the '80s and HST/WFPC2 in the '90s. Science will range from the production of clean CMDs for radial velocity members to detailed multi-element chemical composition studies, from stellar rotational velocities to velocity dispersion at large distances from cluster center checking for the presence of “dark matter”, and more, being all this for huge samples of stars. Next, is a jump of similar size in multiobject spectroscopy of globular cluster systems, with hundreds of
clusters in dozens of galaxies being observed. It is likely that this quantitative, orders of magnitude expansion in the number of observed stars and clusters will result in qualitative progress as well, with many of the open problems of today being happily closed. Then, qualitatively new science may well come from the 3D spectroscopy of cluster cores, with a good chance to make surprising discoveries besides establishing whether or not there is a massive BH lurking at the center of some clusters.

However, in such optimistic scenario one caveat is in order. Experience has shown that when a new facility is offered, with vastly expanded capabilities over similar instruments of the previous generation, then it is relatively easy to conceive a scientifically exciting proposal, to get it approved by a telescope time allocation committee, and then to get the data. Nonetheless, experience has also shown that astronomers that were successful in collecting the data may get stuck with them because of the inadequate hardware, and especially software tools, at disposal for the reduction and scientific analysis of the data. Given their enormous data rate, this is of particular concern for the high-multiplex, multiobject spectrographs and the 3D spectrographs. Without a dedicated effort to prepare the necessary database environment and software tools many scientifically valuable data may remain virtually unused for a very long period of time.

In the next decade (2010-2020), ground based astronomy will be dominated by ALMA and the next generation of the optical/IR extremely large telescopes, CELT, GSMT, ELT, OWL, and whatever. With such large optical/IR telescopes it will be finally possible to directly map the evolution of globular clusters in galaxies all the way to see them in formation, and eventually stick on the wall a poster with a million pixel picture of a $z = 5$ galaxy, with all her young globulars around.