Project: Dynamics and mass models of the central region of globular clusters in the local Milky Way

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Main goals of the proposal:

From the pedagogic point of view our goals are:

- To provide students with the appropriated scientific scenario to acquire experience on photometric and spectroscopic observations of point and extended sources under a formal observational campaign using resources at a professional level.

- To obtain proprietary data that allow the students to learn and practice the procedures of reduction and analysis of astronomical data (photometry and spectroscopy), with the motivation of being part of a project. (not just a classroom lab exercise !)

From the scientific point of view our goals are:

- To acquire data that allow us determine the velocity dispersion profile in the inner region of globular clusters in order to build mass models for them.

- To acquire data that allows the study of the surface brightness distribution of globular clusters that can be used to infer the properties of its stellar mass distribution.

- To study the level of internal motion (rotation, annisotropy, etc) of globular clusters in the Milky Way that can be used to build complete dynamical models.

Instruments

Telescope: P&E 1.6m

Instrument: Espectrografo Cassegrain + CCD Ikon-L + Filters BVR
Dates: May 14, 15

Telescope: B&C 60cm
Instrument: CCD Ikon-L + Filters BVR
Dates: May 16, 17, 18, 19

Pedagogic Aim of the observation

The Undergraduate program in Astronomy at Universidad de Antioquia was born in 2009 hosted by the Instituto de Física. Currently, around 250 students are enrolled in the program, from which we expect to have the first small group of professional astronomers to be graduated by the end of this year.

Being hosted by the Instituto de Física has made the astronomy students at UdeA. to have a very strong formation in theoretical astronomy and astrophysics. However although the university has provided some semi-professional facilities to be used in laboratory activities, we have no local or national professional observational facilities in which advanced students can have proper professional observational experience to strengthen its formation on observational astronomy.
In order to provide our students not only with a strong formation on the theory, but also with a valuable experience and knowledge on observational astronomy, we have established as an academic compromise, to allow each student to take part of a professional observational campaign in a foreign observatory.

Three of our students have already been taking part of such programs at Observatorio Nacional and San Pedro Martir in Mexico. Now we plan to extend this opportunity to new advanced students of our program with this observational plan at Observatorio Pico dos Dias.

Our students already know the details of astronomical image reduction and processing, however, with this experience we plan to ensure their formation is strong enough, not only from the processing point of view, but also from their abilities and experience performing observations in a facility of professional level.

Outline of the scientific problem

Despite the large amount of observational data and the advances in theoretical work, still, there is not yet a convincing model to describe the formation of ancient globular clusters.
In the current scenario of galaxy formation, galaxies are formed in to the deepest regions of the gravitational potential well provided by dark matter halos. Peebles (1984) proposed such an scenario would be also valid to explain the formation of ancient globular clusters. This explanation has been received with great interest by the community since it not only fits within the hierarchical scenario of structure and galaxy formation, but also may help to understand some of the open problems in the standard model, such as the abundance of low mass structures (Klypin et. al. 1999). However, evidence has been found against this scenario. For

example, Odenkirchen et al. (2003) have found tidal tails surrounding globular clusters, something that is not expected if globular clusters form and reside inside extended dark matter halos.

On the other hand, Fall & Ries (1985) propose the formation of globular clusters as a response to instabilities in the hot gaseous halos of massive galaxies. This scenario presents a problem since there are observations that suggest that very low mass galaxies, not massive enough to host a hot gaseous halo, may also have their own globular clusters.

Conroy et. al. (2011) have used density profiles to argue against the presence of dark matter inside globular clusters, while Ibata et. al. (2013) have found that under general conditions it could be possible to find significant fractions of dark matter in globular clusters. Modeling the mass content of globular clusters in the galaxy would help to disentangle the mechanism driving its formation process. Mass modeling would allow to study the mass distribution in the inner region of globular clusters, determining the dominant components (Breddels M. A. et.al. 2013, Adams J. J. et. al., 2012, van den Bosch R.C.E. et. al. 2006) providing light on the problem of the origin of globular clusters.

Methodology

In order to complete this project we propose an observational campaign taking integrated spectra of the central region of the globular clusters (Schiavon et. al. 2005, Lützgendorf et. al. 2012) in two orthogonal directions. Spectroscopic information will be complemented with photometry in BVR bands in order to infer the distribution of stellar mass in the clusters.

Since the period of time available for observation is time of full Moon, observational targets have been selected to satisfy two criteria.

1) In order to increase the signal-to-noise ratio with the glowing background, clusters have been selected to have apparent V magnitudes smaller than $m_v=8$.
2) Clusters should be far enough from the Moon, in order to minimize the contamination from Moonlight. Therefore no cluster closer than 30° to the Moon has been included in the candidate list.

For each cluster two sets of spectra will be taken. One set of three spectra will be taken in the North-South direction while a second set will be taken perpendicular to the former. This would allow us to identify anisotropies in the dynamics of the cluster. An important ingredient on the mass modeling of spheroidal systems.

Spectroscopic measurements will be taken using the Cassegrain Spectrometer in the 1.6P&E Telescope.

Complementary photometric data will be taken in the 0.6mB&C telescope in the BVR bands, in order to complement the analysis with surface brightness distributions of clusters as well as study of stellar populations and ages via color magnitude diagrams. At least 5 expositions per cluster per band will be required.

In order to account for the effects of the Moonlight on the photometric measures, targets will be observed repeatedly in different nights when relative position of the Moon has changed, and therefore all background will be shifted systematically.

If possible, the 0.6mB&C telescope will be used to complete the survey of cluster spectra.

List of Observation targets

Table 1 lists the observational candidate targets sorted according to its distance to the Moon at the first observing night (May the 14^{th}). In order to minimize the effects of the background Moonlight priority will be given to targets at larger distances from the Moon. However, to be able to calibrate our procedures and to compare with previous works, some well know clusters are marked as priority targets, as it is the case of Omega Cen, 47 Tuc, etc.

D. Moon [deg]	Ra [deg]	Dec [deg]	Mv	NGC
82.734	138.011	−64.863	6.2	2808
82.713	15.8096	−70.848	6.4	362
81.525	154.403	−46.411	6.75	3201
*79.438	6.0217	−72.081	3.95	104
*76.216	322.493	12.1669	6.2	7078
*72.349	323.372	−0.8231	6.47	7089
*67.972	325.092	−23.179	7.19	7099
65.023	186.439	−72.659	7.24	4372
64.795	205.547	28.3756	6.19	5272
64.137	198.230	18.1692	7.61	5024
62.108	259.280	43.1364	6.44	6341
61.905	194.896	−70.875	6.91	4833
57.149	189.867	−26.743	7.84	4590
55.057	250.423	36.4603	5.78	6205
*49.740	201.691	−47.477	3.68	5139
49.005	262.978	−67.048	7.73	6362
48.725	287.716	−59.982	5.4	6752
48.209	206.610	−51.373	7.34	5286
40.897	294.998	−30.962	6.32	6809
36.594	265.172	−53.674	5.73	6397

34.209	284.888	−36.632	7.01	6723
31.327	283.764	−30.478	7.6	6715
30.846	261.372	−48.423	7.96	6352
30.349	272.009	−43.706	6.3	6541

Table 1. List of observational targets ordered by priority according to its distance to the Moon (first column). Targets labeled with * are mandatory targets since they are commonly studied object. They will be used to calibrate our procedures.

All objects have been checked to fit in the field of view of the telescope, as well as to fit on the area of the CCD.

Spectra have been modeled with the 900 and 1200 lines/mm grating centered close to 8500 and 5500 Amstrongs (although the grating with 832 lines/mm can also be used to increase the spectral coverage at expenses of lower wavelength resolution). This in order to allow the identification of the Calcium triplet at 8498, 8542 and 8662 Amstrongs (commonly used for kinematics) and Iron and Magnesium lines close to 5200 Amstrongs (commonly used for metalicity). At 8000 Amstrongs the CCD EQ of the Ikon-L camera is still around 60% while at ~5000 it peaks above 80%.

For spectra, exposure times have been estimated in sequences between 180 and 600 seconds (depending on seeing conditions and Moon background brightness) in order to achieve a S/N ratio close to 100.

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