Studying the Outskirts of NGC2682 (M67) open cluster

L. Balaguer-Núñez[1,2], L. Casamiquela[1,2] C. Jordi[1,2], J. L. Muiños[3], D. Galadí-Enríquez[4], E. Masana[1,2]

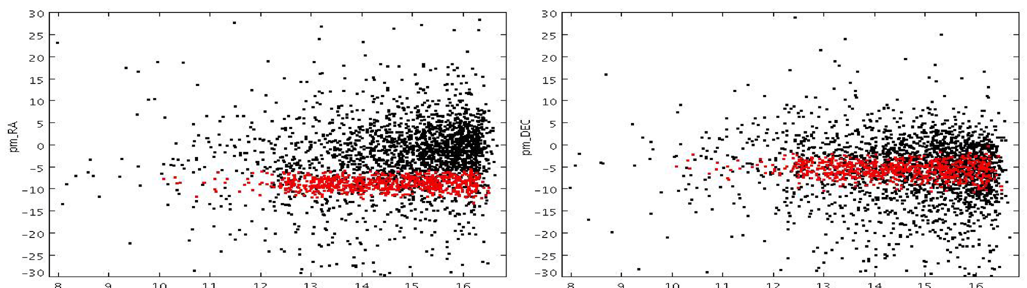
1. Dpt. d'Astronomia i Meteorologia, Universitat de Barcelona, Barcelona, Spain
2. Institut de Ciències del Cosmos ICCUB - IEEC, Barcelona, Spain
3. Real Instituto y Observatorio de la Armada, San Fernando, Spain
4. Centro Astronómico Hispano-Alemán CAHA, Almería, Spain

ABSTRACT

The combination of deep and wide astrometry study together with the best set of Strömgren photometry ever obtained for the open cluster NGC2682 (M67) let us study the physical properties of the stars in the cluster area and analyse its outskirts. The astrometric study covers an area of about 2ºx1.4º and down to r'~17 while our INT-WFC CCD intermediate-band uvby-Hβ photometry covers an area of about 45'x45' down to V~18. The stars of the area selected as cluster members are classified into photometric regions and their physical parameters determined, using uvby-Hβ photometry and standard relations among colour indices for each of the photometric regions of the HR diagram. That allows us to determine reddening, distances, absolute magnitudes, spectral types, effective temperatures, gravities and metallicities in a wider area ever studied, thus providing an astrophysical characterization of the stars in the cluster outskirts. We found stars compatible with astrometric and photometric membership up to 33' from the cluster centre, so meaning 2.6 times the radius quoted in Dias et al (2012), and also found members up to 1.2º with only astrometric criteria. These data will allow us to the most complete study of the cluster structure, dynamics and mass segregation up to date.

1. New Proper Motions Study

New absolute proper motions for 2841 stars have been calculated on the basis of new measurements made with the Meridian Circle of San Fernando CMASF at El Leoncito (Argentina). First epoch data have been taken from plates POSSI (1951.9) on the USNO-A.2 catalogue (median σ_{RA} = 0".25, σ_{DEC} = 0".29). The second epoch is taken from CMC15 (2001 for this zone) and the new measurements taken with CMASF (2010). When the three epochs where available a linear fit was used. For stars with no intermediate data (CMC15 2013) nominal errors of the proper motions are larger (see bottom left graph in the figure below). Final data cover an area of 2°x1.4° with approximate magnitude limits 9 < r'< 17. To check for magnitude trends in proper motions we have plotted (see figure below) our selection of cluster members as red circles. We find no trend with magnitude.



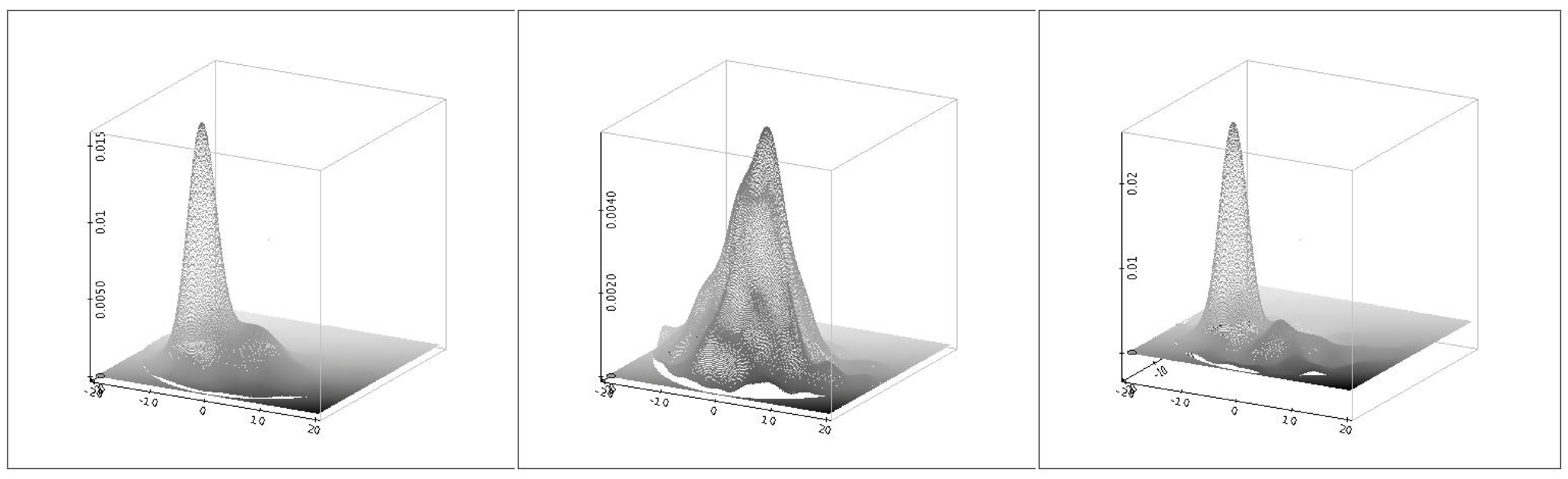
2. Membership Probabilities

The parametric approach: We assume the existence of two populations in the vector-point diagram (VPD): cluster and field stars. A circular Gaussian model is adopted for the cluster distribution while a bivariate (elliptical) Gaussian describes the field. We apply a 9-parametric Gaussian model following Balaguer-Núñez et al (2004b, 2005, 2007). Our implementation takes into account the individual errors of the proper motions measurements (Zhao & He 1990).

	n_c	$\mu_\alpha\cos\delta$	μ_δ	σ_c	$\sigma_{\mu\alpha\cos\delta}$	$\sigma_{\mu\delta}$	ρ
M 67	0.256	-8.77	-5.47	1.28			
	±0.011	± 0.09	± 0.09	±0.06			
Field		-2.84	-5.91		+7.61	6.92	-0.15
		± 0.04	± 0.19		± 0.01	± 0.10	±0.01

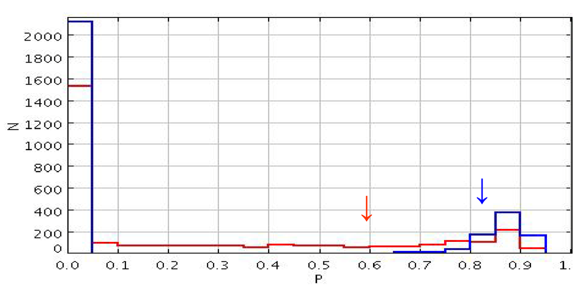
Distribution parameters and their uncertainties: n_c measures the volume of the cluster frequency function, $\mu_\alpha\cos\delta$ and μ_δ are then mean absolute proper motions, σ_c and $\sigma_{\mu\alpha\cos\delta}$ and $\sigma_{\mu\delta}$ are the dispersions of the Gaussians fitted to the cluster and field distributions, and ρ is the correlation for the field function. The units of μ and σ are mas yr^{-1}.

The non-parametric approach: We perform an empirical determination of the frequency functions, ψ, from the VPD without relying on any previous assumption about their profiles (Balaguer-Núñez et al 2004b, 2005, 2007; Galadí-Enríquez et al. 1998). In the area occupied by the cluster, the ψ is made up from two contributions: cluster and field stars. To disentangle the two populations, we studied the VPD for the area outside a circle centred on the cluster. The maximum of the cluster PDF is located at ($\mu_\alpha\cos\delta$, μ_δ) = (-8,8 ± 0.2, -5.9 ± 0.2) mas yr^{-1}.



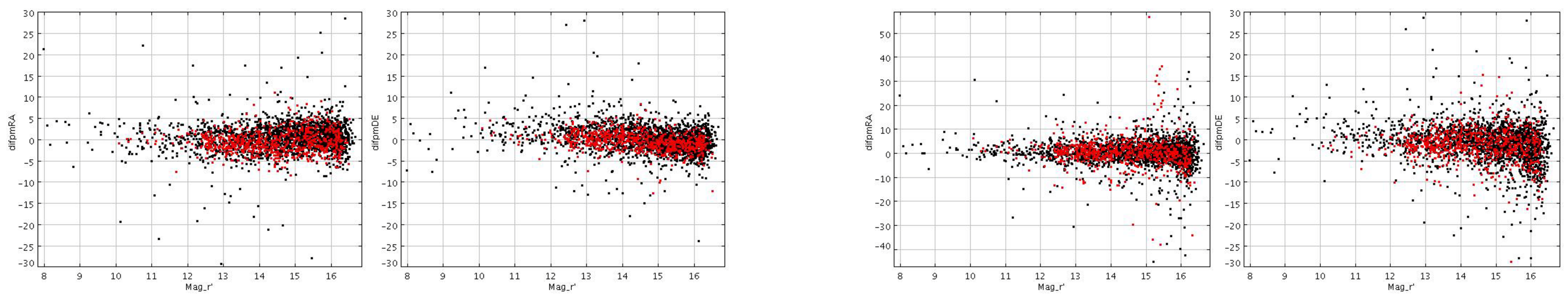
Empirical PDFs in the VPD. Left: ψ_{c+f} mixed sample from the inner circle of 30' centred on the point of maximum spatial density of stars. Centre: ψ_f field population from outside this circle. Right: ψ_c cluster population of M67.

Membership probabilities are computed for both approaches (see histogram below). The non-parametric technique yields an expected number of cluster members from the integrated volume of the cluster frequency function in the VPD areas of high cluster density. The expected number of cluster members in this VPD area is 633. Sorting the sample in order of decreasing membership probability, the first 633 are the most probable members. The minimum value for the non-parametric probability (for the 633th star) is P_{NP} = 0.825. Accepting the same volume for the parametric approach gives us P_P = 0.59. We accept as members those classified as such by at least one of the methods. This way we get a list of 727 members.



Membership probabilities for all stars: parametric (in red) and non parametric (in blue) methods. Arrows indicating limiting probability

3. Comparison with PPMXL and UCAC4 Proper Motions

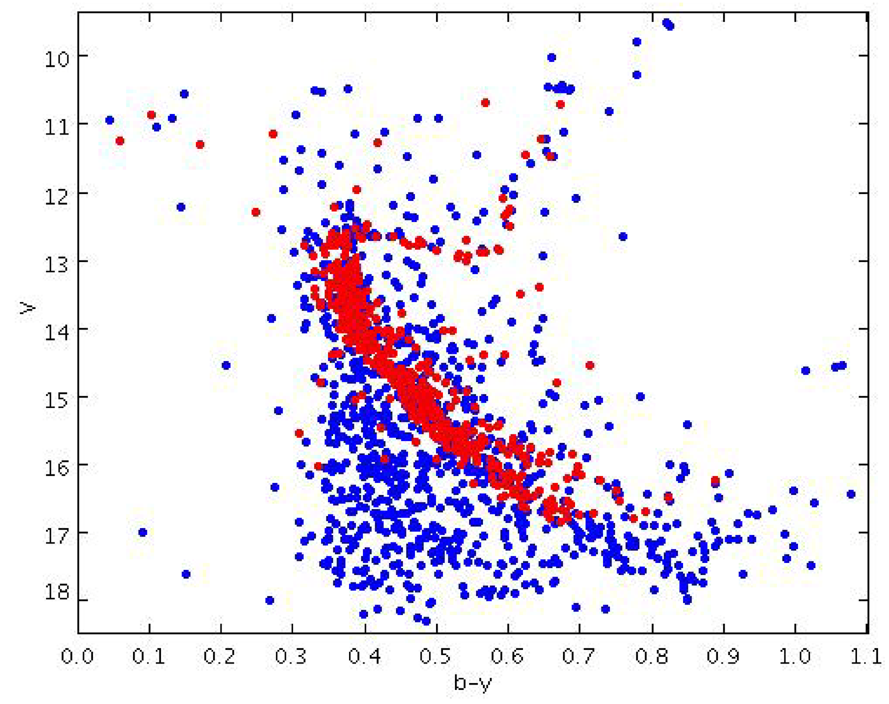


We compare our absolute proper motions with those of PPMXL (Roeser et al. 2010) with 2837 stars in common (left figure), and the latest release UCAC4 (Zacharias et al. 2012) with 2754 common stars (right figure). We also check on magnitude trends using our selection of cluster members (in red). We can see that UCAC4 proper motions for the cluster members show a slight trend with magnitude at r'>16 (much smaller than UCAC2 and UCAC3 releases that hold strong trend with magnitude).

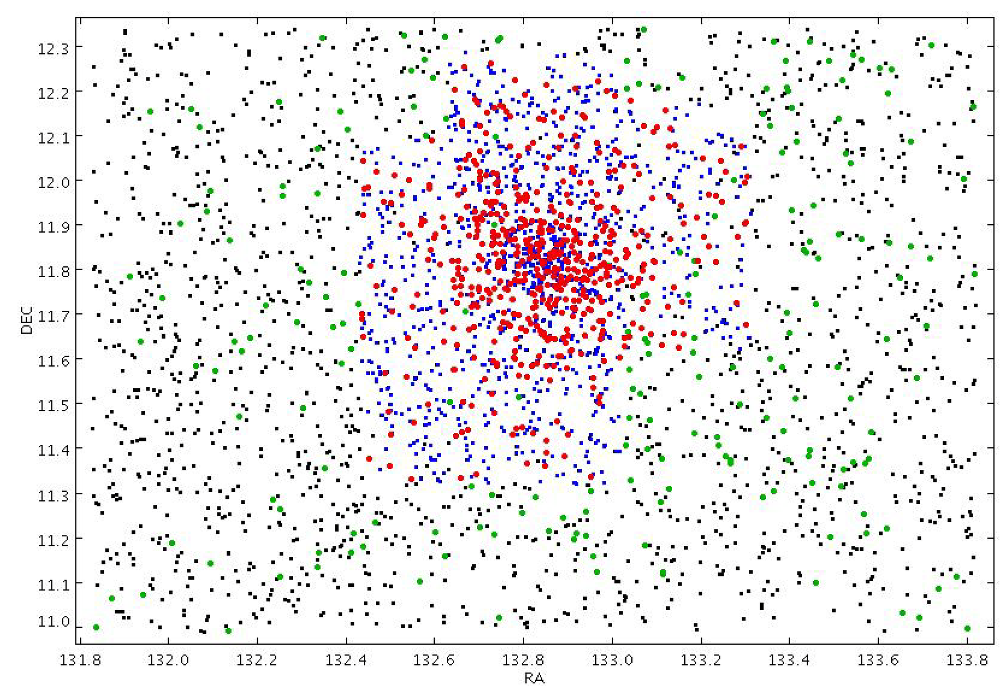
4. New Strömgren photometry

M67 stars were regularly observed as standard for runs with the WFC of the 2.5 m Isaac Newton Telescope in La Palma. The cluster was observed several times in each Strömgren filter covering a field of 45'x45' and obtaining a total of **1518** stars with complete photometry up to a limiting magnitude V ~ 18.

Run	Filters	Pointings
10 March 2007	uvby	8
31 January 2008	uvby	14
18 January 2009	uvby + Hβ	12 + 13



The segregation of members based on proper motions data, that is described in Sec. 2, was combined with our photometry. We found **524** members marked in red in the colour-magnitude diagram above.



Spatial distribution of M67 members. The 2841 stars with astrometry are marked in black, the 1518 stars with photometry are in blue. Astrometric member stars (727) are marked in green, while those with astrometry and photometry are marked in red.

We highlight that members can be found up to 1.2° from the cluster center in the astrometric selection and up to 33' in the photometry and astrometry selection. That means **2.6 times the radius** quoted in Dias et al. (2012)

5. Results

From a total of 498 member stars with complete photometry, we were able to calculate individual physical parameters (Jordi et al 1997). We found the following mean values for the cluster:

E(b-y) = 0.04 ±0.01 mag   Distance = 815 ±145 pc   [Fe/H] = -0.1 ±0.2.

The area covered by our new wider and deeper cluster segregation study allows us to improve our knowledge of the corona of M67. These are only the first results on a complete study of its structure. We will be able to derive structural parameters and discuss the spatial dependence of the luminosity and mass functions. We will analyze the spatial distribution of mass functions and the cluster mass segregation, as well as the dynamical implications in a forthcoming paper.