Mem. S.A.It. Vol. 79, 360
© SAIt 2008
Memorie della

The BSS and binary content of NGC 5024 (M53): a combined LBT/HST study

G. Beccari[1], L. Pulone[3], F.R. Ferraro[2], B. Lanzoni[2], F. Fusi Pecci[1], R.T. Rood[4], E. Giallongo[3], R. Ragazzoni[5], A. Grazian[3], A. Baruffolo[5], C. De Santis[3], E. Diolaiti[1], A. Di Paola[3], J. Farinato[5], A. Fontana[3], S. Gallozzi[3], F. Gasparo[6], G. Gentile[5], R. Green[7], J. Hill[7], O. Kuhn[7], N. Menci[3], F. Pasian[6], F. Pedichini[3], R. Smareglia[6], R. Speziali[3], V. Testa[3], D. Thompson[7], E. Vernet[8], and R.M. Wagner[7]

[1] INAF, Osservatorio Astronomico di Bologna, via Ranzani 1, I-40127 Bologna, Italy, e-mail: giacomo.beccari@oabo.inaf.it
[2] Università di Bologna, Via Ranzani 1, I-40127, Bologna, Italy
[3] INAF, Osservatorio Astronomico di Roma, Via Frascati 33, I-00040, Monteporzio, Italy
[4] Astronomy Department, University of Virginia, P.O. Box 400325, Charlottesville, VA 22904
[5] INAF, Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio, 5, I-35122 Padova, Italy
[6] INAF, Osservatorio Astronomico di Trieste, Via G.B. Tiepolo 11, I-34131 Trieste, Italy
[7] Large Binocular Telescope Observatory, University of Arizona, 933 N. Cherry Ave., Tucson, AZ 85721-0065
[8] INAF, Osservatorio Astronomico di Arcetri, Largo E. Fermi 5, I-50125, Firenze, Italy

Abstract. We present deep, wide-field imaging of the Globular Cluster NGC 5024, obtained at the Large Binocular Telescope. Images in U, B and V were obtained with the Large Binocular Camera, allowing to resolve the stars down to U ∼25.5 in a field of view of $25' \times 24'$. The combination of short and deep exposures allowed the construction of color-magnitude diagrams spanning all the canonical sequences from the tip of the red giant brunch down to 4 magnitudes below the main sequence Turn Off. Combining this data with high resolution ACS@HST archive images of the central region of the cluster we selected a well defined population of blue stragglers stars, confirming that they have a bimodal radial distribution. Moreover we determined the binary frequency in the outer regions ($r > 200''$) of the cluster, finding that about 14% of the stars in these regions are in binary systems.

Key words. Globular cluster: M53; Stars: blue stragglers;

1. Introduction

Globular Clusters (GCs) are ideal astrophysical laboratories for studying the evolution of

Send offprint requests to: G. Beccari

single stars, as well as of binary systems. In particular, the evolution and the dynamical interactions of binary systems in high-density environments can generate objects (like Blue Straggler Stars, X-ray binaries, millisecond pulsars, etc.) that cannot be explained by standard stellar evolution. In this respect the most common exotic objects are the so-called Blue Straggler Stars (BSSs). BSSs are core-hydrogen burning stars with masses larger than normal cluster stars, and their origin is still a puzzle. Two mechanisms have been proposed for their formation: mass-transfer (MT) between binary companions, which mainly evolve in isolation in low density environments, or merger of stars driven by stellar collisions (COL), which are particularly efficient in high density regions. In recent years we have determined the BSS radial distribution in a number of GCs (see references in Lanzoni et al. 2007a, hereafter L07a), finding that it is bimodal (i.e., with a peak in the centre and an upturn in the external regions) in at least 8 cases. By supporting these observations with accurate dynamical simulations, we have demonstrated that $\sim$20-40% of the entire BSS population in the "bimodal GCs" must be MT-BSSs, most of them still populating the cluster outskirts. A negligible fraction of MT-BSSs is instead required in the case of GCs with non-bimodal radial distribution. Here we study the BSS and binary populations in the GC NGC5024 (M53), taking advantage of deep wide field imaging from the blue channel of the Large Binocular Camera (LBC-Blue) mounted at Large Binocular Telescope (LBT), properly combined with ACS@HST archive data.

2. Observations and data reduction

The photometric data used here consist of two sets. *(i) The wide field set* consist of deep multi-filter (U, B and V; see Table 1) wide-field images, secured during the Science Demonstration Time (SDT) of LBC-Blue (Ragazzoni et al. 2006; Giallongo et al. 2007) mounted on the LBT, sited at Mount Graham, Arizona (Hill et al. 2006). The LBC is a wide-field imager which provides an effective $23' \times 23'$ field of view, sampled at 0.224 arcsec/pixel over four chips of 2048×4608 pixels each. LBC-Blue is optimized for the UV–blue wavelengths, from 320 to 500 nm, and is equipped with the U, B, V, g and r filters. In the images used here the core of the cluster is positioned in the central chip (namely #2) of the LBC-Blue CCD mosaic. The raw LBC images were corrected for bias and flat field, and the overscan region was trimmed using a pipeline from LBC-team at Rome Astronomical Observatory[1] specifically developed for LBC image pre-reduction. The source detection and relative photometry was performed independently on each U, V and B image, using the PSF-fitting code DoPHOT (Schechter, Mateo & Saha 1993). Further details on the reduction procedures and calibration are given in a forthcoming paper (Beccari et al. 2007a in preparation). Here notice that we reduced the short and long exposure images separately in order to obtain a bright *and* a deep sample. We derived accurate ($\sigma < 0''.2$) absolute astrometry by a proper cross-correlation with a 2MASS catalogue covering the same region. A final catalog listing the instrumental U, B and V magnitudes for all the stars in each CCD field was thus obtained. *(ii) The high spatial resolution set* consists of a set of ACS@HST images of the core region obtained through the F606W (V_{606}) and F816W (I_{814}) filters (GO-10775;PI: Sarajedini). We used only the images acquired with short exposure time (45s) which allow us to sample stars from horizontal branch (HB) level down to 2 magnitudes below the main sequence turn off (MS-TO). Since stellar crowding is low in

Table 1. Photometric data

Filter	# of images	Exp Time [sec]
U	2	500
–	1	20
B	2	300
–	1	10
V	8	300
–	1	10

[1] http://lbc.oa-roma.inaf.it/

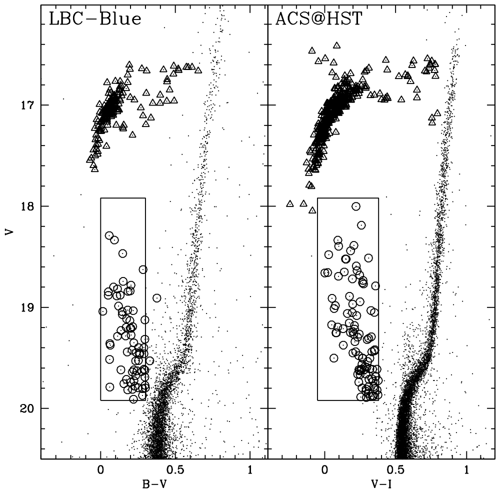

Fig. 1. CMDs obtained from LBC-Blue (left panel) and ACS@HST (right panel) data.

these images, we decided to perform aperture photometry using the SExtractor photometric package (Bertin et al. 1996), with an aperture radius of 0.125″ (corresponding to a FWHM i.e. 5 pixels). By using more than 2500 bright stars in LBC-Blue catalogue as *secondary astrometric standards*, we found an astrometric solution with a global uncertainty ≤ 0.″2 both in RA and Dec for stars in ACS catalogue. A master, homogeneous catalogue of magnitudes and absolute coordinates including all the stars in the HST and the LBC-Blue catalogues was finally produced.

3. The *bright* sample: the BSS radial distribution

In Figure 1 we show the CMD of the LBC-Blue (left panel) and the ACS catalogue (right panel). The selected BSSs and HB stars (assumed as reference population) are marked with open circles and triangles, respectively. The BSS selection box was defined as the region in the CMDs containing all the BSSs in common with Rey et al. (1998, hereafter R98), who studied the BSS radial distribution inside a region of ∼ 9′ from the cluster center. Notice that also SX Phoenicis and

Table 2. Selected Populations

Catalogue	# of BSSs	# of HBs
ACS	96	363
LBC-Blue	71	183

RRlyrae stars, identified by comparing our catalogues with previously published works (see Jeon et al. 2003; Clement et al. 2001, for recent SX Phoenicis and RRlyrae catalogues respectively), were included in the BSS and HB population respectively. Being variable stars observed at random phase, the SX Phoenicis stars listed in Jeon et al. (2003) catalogue have been identified in our sample and counted as BSS independently of their position in CMD. Further details on selection criteria will be described in Beccari et al. (2007b, in preparation). In Table 2 we report the number of BSSs and HBs selected in the ACS and LBC-Blue catalogues. According to L07a, we divided our catalogue in concentric annuli centered on the cluster center (from Harris et al. 1996). Then we counted the number of BSSs, HBs and derived them ratio in each annulus. In Figure 2 we show the radial distribution of BSSs normalized to the HB population. It clearly shows a bimodal radial distribution of BSSs with a high frequency in the inner and outer regions, but a distinct dip in the intermediate region. Notice that, taking advantage of the wide field capabilities of LBC-Blue, we derived the BSS radial distribution, up to $r \simeq 14.2'$ from the centre. Figure 2 resample the result showed by R98 with the exception that our data allow us to confirm the persistence of a BSS upturn from the ∼ 9′ explored by R98 to ∼ 14′.2 from the cluster center. Moreover this distribution is similar to that found in several GCs studied with a similar observational strategy proposed here (e.g. M3, 47 Tuc, NGC6752, M5, M55; see L07a, and reference therein). Recently, extensive dynamical simulations based on an updated version of the code described by Sigurdsson & Phinney (1995), have been successfully used to properly reproduce the BSS radial distribution (see Mapelli et al. 2006; Lanzoni et al. 2007a,b).

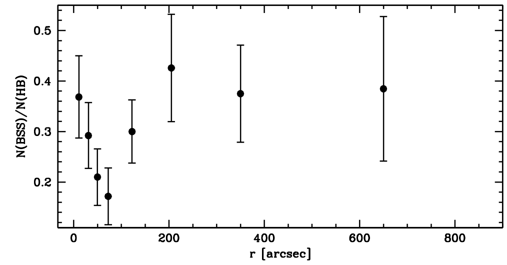

Fig. 2. Radial distribution of BSSs normalized to HB stars.

The simulations demonstrate that in GCs showing a BSS bimodal radial distribution, the observed central peak is mainly due to COL-BSSs formed in the core and/or MT-BSSs sunk to the centre because of dynamical friction effects, while the *external* rising branch should be made of MT-BSSs evolving in isolation in the cluster outskirts. Recently Ferraro et al. (2006), from high resolution FLAMES spectroscopy, discovered that a sub-population of BSSs in 47Tuc (whose BSS population has bimodal radial distribution) shows a significant depletion in the carbon and oxygen surface abundances, with respect to the dominant BSS population and the normal cluster stars. They interpret this chemical anomaly as a signature of the MT formation process for BSSs. Hence detailed simulations and high resolution spectroscopy are crucial to finally unveil the formation mechanism of these peculiar objects. The result shown here contributes to the observational characterization of BSSs in M53. Moreover, we show once again the importance of an observational approach which combines the high resolution HST capabilities in the core-crowded regions and big telescope like LBT equipped with wide field capabilities.

4. The *deep* sample: the binary fraction in the external regions

The LBC-Blue camera is optimized for imaging in the U and B bands. In order to check the camera capability, we acquired a series of deep U, B and V images of the cluster during the SDT. Here we present the first very preliminary photometry of an external chip (namely #

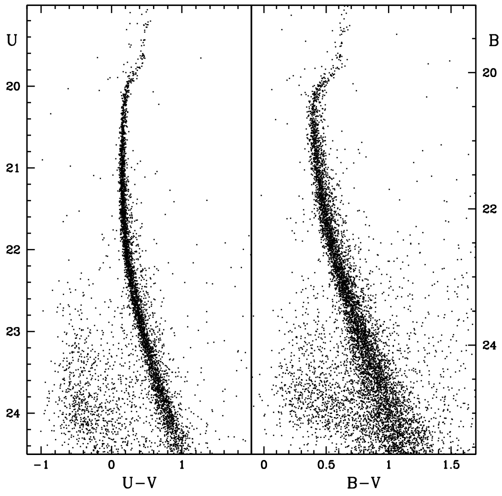

Fig. 3. (U, $U - V$; left panel) and (B, $B - V$; right panel) CMD obtained with the external chip (namely # 3) the LBC-Blue mosaic.

3) of the camera mosaic. This allows us to sample a region with a radial range spanning from $r \simeq 4'$, to $\simeq 11.6'$ from the centre. Because of the very low crowding conditions of the external regions, analyzing this external chip is the optimal choice for an efficient test of the performance and capability of the camera. The photometry reduction is described in section 2. Figure 3 shows the CMD in the $(U, U - V)$ and $(B, B - V)$ planes. These are the deepest CMDs ever published for this cluster. With a 300s B and 500s U exposure we reached magnitudes $B \simeq 25.5$ and $U \simeq 24.5$ with a S/N ~ 5 according with the expected performances of the "telescope plus camera" system. The CMD plotted in Figure 3 shows a very well defined MS with a secondary MS (SMS) is clearly visible. This is likely generated by a binary population. A non-resolved binary system in a globular cluster is seen as a single star with a flux equal to the sum of the fluxes of the two components. The shift in magnitude of the binary system can be viewed as the effect of the secondary star that perturbs the magnitude of the primary. The shift depends on the mass ratio of the two components (q = M2/M1) ranges between 0 and 1; this range in mass ratio requires that a binary system can appear at most 0.752

mag brighter than the primary component (see Sollima et al. 2007, hereafter S07). In order to perform a preliminary estimate of the binary fraction ξ in the considered region of M53 we used the same procedure described by S07; details will be given in Beccari et al. (2007b). Very quickly, we performed completeness experiments on the images and, using the simulated catalogue, we generated a simulated binary population with a distribution $f(q)$. The value of ξ derives from the comparison between the colour distribution of simulated stars and that in the observed CMD. We assumed a distribution constructed by extracting random pairs of stars using the initial mass function of De Marchi et al. (2005). Using this method we derive a best value in percentage of binary fraction of 14% in the external region of M53.

5. Conclusions

We have obtained a multiband deep photometry of the GC NGC5024 through data acquired during the Science Demonstration Time of the LBC-Blue mounted on LBT. The data allow us to obtain CMDs in the *U*, *B* and *V* bands, spanning all the canonical sequences from the tip of the red giant branch, down to 4 magnitudes below the turn Off. There are two separate samples: 1) The *bright* sample: the wide field capabilities of LBC-Blue properly combined with high resolution properties of ACS@HST, allow us to resolve the main cluster stellar populations from the very central regions to a distance of $\simeq$ 14.2′. We studied the BSSs radial distribution compared to HB stars, and we found it to be bimodal. By comparison with other GCs with a similar BSS bimodal radial distribution, we could assume that there are two populations of BSSs in M53, generated from two different evolutionary mechanisms. Further investigations through theoretical simulations and high resolution spectroscopy are necessary to clarify the mechanisms at the origin of this population. 2) The *deep* sample: the obtained $(U, U-V)$ and $(B, B-V)$ CMDs of an external region of the cluster demonstrate that LBC-Blue, optimized in the UV–blue wavelengths, reaches the planned performances. We used these data to a preliminary estimate the binary fraction finding it to be $\sim$ 14%.

Acknowledgements. Based on data acquired using the Large Binocular Telescope (LBT). This research made use of the NASA/ADS database. Financial support for this study was provided by INAF, ASI and the MIUR.

References

Bertin E., Arnouts S. 1996, A&AS, 117, 393
Clement, C. M., et al. 2001, AJ, 122, 2587
De Marchi G., Paresce F., & Portegies Zwart S. 2005, in “The Initial Mass Function 50 Years Later”, Springer-Verlag (Dordrecht), ASSL Vol. 327, p. 77
Ferraro, F. R. et al. 2006, ApJ, 647, L53
Giallongo, E., Ragazzoni, R., & Grazian, A. et al. 2007 submitted
Harris, W.E. 1996, AJ, 112, 1487
Hill, J. M., Green, R. F., & Slagle, J. H. 2006, Proc. SPIE, 6267, 62670Y
Jeon, Y.-B., Lee, M. G., Kim, S.-L., & Lee, H. 2003, AJ, 125, 3165
Lanzoni, B., Dalessandro, E., Perina, S., Ferraro, F. R., Rood, R. T., & Sollima, A. 2007, ArXiv e-prints, 709, arXiv:0709.1609 (L07a)
Lanzoni, B., Dalessandro, E., Ferraro, F. R., Mancini, C., Beccari, G., Rood, R. T., Mapelli, M., & Sigurdsson, S. 2007, ApJ, 663, 267
Mapelli, M., Sigurdsson, S., Ferraro, F. R., Colpi, M., Possenti, A., & Lanzoni, B. 2006, MNRAS, 373, 361
Ragazzoni, R., et al. 2006, Proc. SPIE, 6267, 626710
Rey, S.-C., Lee, Y.-W., Byun, Y.-I., & Chun, M.-S. 1998, AJ, 116, 1775 (R98)
Robin A. C., Reil C., Derrire S., Picaud S. 2003, A&A, 409, 523
Schechter, P. L., Mateo, M., & Saha, A. 1993, PASP, 105, 1342
Sigurdsson, S., & Phinney, E. S. 1995, ApJS, 99, 609
Sollima, A., Beccari, G., Ferraro, F. R., Fusi Pecci, F., & Sarajedini, A. 2007, MNRAS, 380, 781