Proc. IV Serbian-Bulgarian Astronomical Conference,
Belgrade 21–24 April 2004,
eds. M. S. Dimitrijević, V. Golev, L. Č. Popović, M. Tsvetkov,
Publ. Astron. Soc. "Rudjer Bošković" No 5, 2005, 167 - 173 *Contributed paper*

BVR PHOTOMETRY OF THE OUTER REGIONS OF THE STARBURST GALAXY M 82

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Abstract. We present BVR CCD photometry of stellar and non-stellar objects in the outer regions of the starburst galaxy M 82 carried out with IRAF software package. The CCD images were obtained with the 2m NAO-Rozhen telescope in May 2003 and cover a field of $\sim 15' \times 7'$, centered on M 82. Combining theoretical predictions and observational data for typical magnitudes and colors of globular clusters (GC), several GC candidates were selected on the color-magnitude diagrams (CMD). They form two distinctive groups most probably due to age differences.

1. INTRODUCTION

The prototype starburst galaxy M 82 is one of the most attractive objects for observers ever since Lynds and Sandage (1963) found evidence for energetic events in its central region, now known as a site of a huge starbursts. This starbursts is thought to have been triggered by interaction that happened $\sim 10^8$ *yrs* ago, (Achtermann and Lacy, 1995) between M 82 and the more massive galaxy M 81, host of the M 81 group of galaxies. Several bright knots in the central region (O'Connell and Mangano, 1978) have been resolved into numerous luminous ($L \sim 4 \times 10^6 L_\odot$), young ($\sim 50 Myr$), massive ($\sim 10^5 M_\odot$) stellar clusters, called "super star clusters" (SSC). In terms of age, SSC resemble the open clusters while they are as massive as globular clusters (GCs) (O' Connell et al., 1995; de Grijs and O'Connell, 2001). Most probably only the most massive and compact of these young systems (if they survive dynamically for a long time-scale) are going to evolve into old Milky Way like globular clusters (de Grijs, Bastian and Lamers, 2003). Therefore it is worth to investigate the older GC system in the outer parts of a galaxy with both very young SSCs and older GCs; it would contribute to a more full understanding of the starburst and its propagation. The abundance and spatial distribution of GCs can serve to test merger and accretion

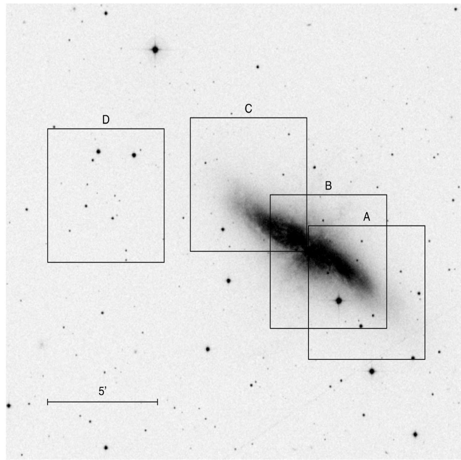

Figure 1: Digitized sky survey image of M 82. The footprints indicates the regions of the 2m NAO-Rozhen telescope observations.

theories (Brodie, 1993). Collisions and mergers of galaxies trigger bursts of "second-generation" star and cluster populations (Schweizer, 2002). Generally, there are three proposed scenarios of GCs formation depending on whether GCs formed before, simultaneously with or after the host galaxy (Fall and Rees, 1988; Schweizer, 1997, 2004).

Supposing a presence of possible intermediate-age GCs population, it is worthwhile to carry out investigation for GCs around M 82. In addition, the proximity of M 82 makes this galaxy an ideal target to study the relationship between galaxy interactions and GCs formation. The small size of globular clusters, $r \leq 40\,pc$, limits the distance range of their visual identification with ground based telescopes. At $3.9\,Mpc$ (Sakai and Madore, 1999) M 82 GCs with similar sizes are expected to has apparent angular diameter of $\sim 2''$. In comparison with the seeing mean value (see Table 1) of $\sim 1.4''$ for our observations, it is very difficult easily to resolve the GCs in virtue of their visual size. More promising is to use color criteria in order to establish the object's affiliation. Recently, Saito et al. (2003) performed a search for possible GC population in the central $6'$ ($6.8\,Kpc$) of M 82. The main goal of our photometry survey is to select GCs candidates on the base of their colors in two outer regions of M 82 (fields A and C in Fig. 1).

2. OBSERVATIONS, REDUCTIONS AND PHOTOMETRY

2.1. OBSERVATIONS

The CCD BVR images of the galaxy M 82 has been observed with the 2m telescope of the Rozhen National Astronomical Observatory between 01-05 May 2003. The observational conditions and the positions of the fields, covering the M 82 and the field with standards (Fig. 1) are summarized in Table 1. The 1024×1024 pixel

Table 1: Log of observations

Date	Field	Field's center α (2000.0) δ (2000.0)	Filter	Exposure [sec]	Seeing [$arcsec$] (FWHM)	Airmass X
05.05.2003	A	09:55:20.72	B	1200	1.2	1.390
		+69:39:21.19	V	400	1.1	1.517
			R	160	1.0	1.424
03.05.2003	B	09:55:41.83	B	1800	1.9	1.518
		+69:40:26.26	V	400	1.5	1.516
			R	160	1.3	1.559
03.05.2003	C	09:56:26.51	B	1200	1.8	1.308
		+69:43:11.10	V	400	1.4	1.383
			R	160	1.3	1.319
03.05.2003	D	09:57:40.64	B	300	1.3	1.183
	photometric	+69:42:11.07	V	75	1.2	1.186
	standards		R	50	1.3	1.188

CCD camera, with scale $12.8\,''/mm$, provide a field of $5,3' \times 5,3'$ with scale of $0.31 \times 0.31\ ''/pixel$. The readout noise is 4.93.

2.2. REDUCTIONS AND PHOTOMETRY

The routine preliminary image processing (including subtraction of bias level, flat fielding and cosmic rays filtering), was performed using the Rozhen software (Georgiev, 1995). The images in each filter were aligned and combined using the centers of the bright stars as reference points. All requirements (for flux conserve, read noise, exposure time etc.) in the image combining procedures for correct subsequent photometry were fulfilled.

All the photometry procedures were done with DAOPHOT under IRAF. The objects in all frames were selected using the automatic star finding procedure DAOFIND. After visual inspection of the images a few faint objects omitted by DOAOFIND and suspected as a potential GCs candidates were added to the lists of objects for photometry. Then we have performed PSF photometry with the DAOPHOT procedure ALLSTAR. The output photometry lists were matched to leave only those objects simultaneously detected in the three filters.

The calibration of instrumental magnitudes was done using ~ 20 local standards (Afanasiev et al., 1990) found nearby M 82 (see Fig. 1). The aperture photometry for these standards was performed using PHOT found in DAOPHOT package. The resulting transformation equations are:

$$B = b - 1.23_{\pm 0.21} - 1.50\,X - 0.01_{\pm 0.24}\,(b - v)$$

$$V = v - 0.71_{\pm 0.18} - 0.80\,X - 0.07_{\pm 0.18}\,(b - v)$$

$$R = r - 0.87_{\pm 0.41} - 0.81\,X - 0.07_{\pm 0.38}\,(v - r)$$

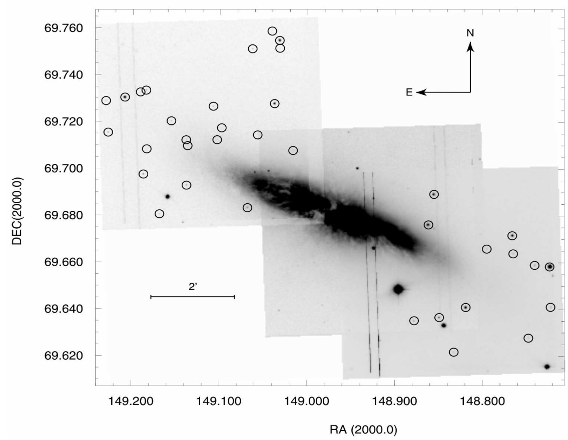

Figure 2: Mosaic view of M 82. With empty circles are indicated all objects placed in the CM diagrams.

where the b, v, r and B, V, R are the instrumental and standard magnitudes, respectively, in the B, V and R filters. X is the air mass.

Thorough investigations have been done of the core starbursts regions (de Grijs et al., 2003; Lipscy and Plavchan, 2004) and near the galaxy plane (Notni et al., 1996; Saito et al., 2003). Our images are not as much deep and doesn't possess the required resolution to carry out trustworthy photometry of common objects in the same regions. That is why comparison between our and early made photometry was not performed.

The colors were de-reddened and the magnitudes extinction-corrected using on-line data available at NED (`http://nedwww.ipac.caltech.edu/`) based on Schlegel (1998) maps. For the foreground extinction in the line of site toward M 82 we adopt $E(B-V) = 0.159,\ E(V-R) = 0.102,\ A_B = 0.685,\ A_V = 0.526,\ A_R = 0.424$.

An estimate for the Galactic foreground star contamination have been obtained using stellar population synthesis model of the Galaxy provided by Robin et al. (2003). The model predicts 5 and 11 foreground stars in 1.873 arcminutes^2 field falling in the GCs candidates magnitude and color range V_0 vs. $(B-V)_0$ and $(V-R)_0$, respectively (see Sect. 3).

3. PRELIMINARY SEARCH FOR GLOBULAR CLUSTERS CANDIDATES

We performed a preliminary inspection for GCs candidates outside the disk of M 82 (Fig. 2) on the basis of their colors and magnitudes. The CM diagrams of objects in fields A and C are plotted in Fig. 3. (The objects in field B need additional photometry and were not taken into consideration. Their analysis will be complemented with data from the Rozhen data archive in a forthcoming paper.)

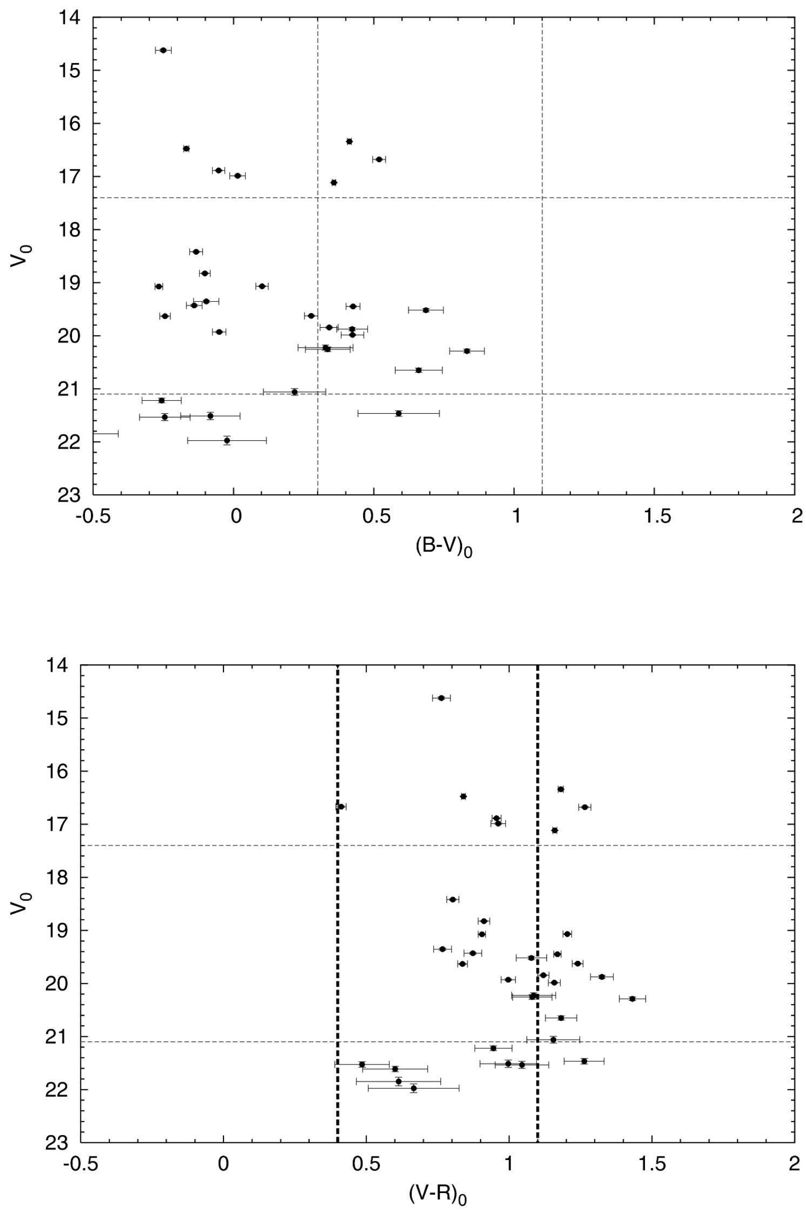

Figure 3: TOP: The V_0 vs. $(B-V)_0$ color magnitude diagram for fields A and C (Fig. 2). Dashed horizontal and vertical lines define the range of the colors and magnitudes values for GCs given by theoretical predictions for different ages and metallicities (cf. text). **BOTTOM:** The same like TOP panel but for V_0 vs. $(V-R)_0$. The $(V-R)_0$ range is marked with different line because it is defined by observational predictions (cf. text).

The expected loci of GCs candidates on diagrams V_0 vs. $(B-V)_0$ and V_0 vs. $(V-R)_0$ are delineated in Fig. 3. The theoretical range of magnitudes and colors is adopted from the models of Fritze (2004) that cover ages from 0.3 to 12 Gyr and metallicities $[Fe/H] = -1.7$ -0.4 and $+0.4$. We have used the extreme values of above quantities to extract the limiting theoretical colors and magnitudes used in the CM diagrams. Unfortunately, the Fritze models do not provide synthetic $(V-R)_0$ color. For that color we impose observational limits, based on the McMaster catalog for Galactic globulars (Harris, 1996).

There are ~ 20 objects that fall within the range $0.3 \leq (B-V)_0 \leq 1.1$, respectively $0.4 \leq (V-R)_0 \leq 1.1$, for $17.4 \leq V_0 \leq 21.1$, typical for GCs (Fig. 3). Their magnitudes are comparable with the median values for globular cluster systems in galaxies outside the Local group ($-6.1 \leq M_V \leq -10.1$; Harris, 1991). We have ~ 8 objects in each panel brighter than $17^m.4$. These are foreground stars since the distance modulus to M 82 is $(m-M)_0 = 27^m.9 \pm 0.16$ (Sakai and Madore, 1999). The theoretical predictions, based on the elaborated model of the Galaxy (Robin et al., 2003), also shows that the foreground contamination in the above mentioned color and magnitude ranges are of 5 and 11 foreground stars, respectively. This number of predicted objects is below the number of candidates and thus we expect that most of the selected objects in that color magnitude regions are GCs candidates.

It is worth to mention at this early stage of our GC population study in M 82 that separation of GCs candidates into two groups is observed. The first one, having a mean colors of $(B-V)_0 \approx 0.4$, $(V-R)_0 \approx 1.1$ and magnitudes $19 \leq V \leq 21.1$ are most presumably contain Milky Way type GCs. Some of the second one, with bluer colors and higher V_0 magnitudes are probably younger second generation GC population. The other possible classification for these objects are to be LBV, multiple star systems or most massive red supergiants.

Color distributions of GC systems around all type galaxies are found to be bimodal, as in our case. Their blue peaks seem to be fairly universal and very similar to that of the Milky Way halo GCs. Such a populations originates in the last encounter between interacting galaxies, namely between M 81 and M 82. More over the young GC time scales in M 82 are the same as those in M 81 and also bimodal color and age distribution are observed (Chandar et al., 2001). The metallicity also plays a key role in the GC colors and should be taken into account. It is very difficult solely on photometrical criteria to say whether the color of the corresponding sample is due to its age or metallicity.

For more trustworthy conclusions concerning the age and metallicity are needed additional investigations on the basis of their spectra and deep space imaging of these objects.

4. CONCLUSIONS

We present BVR CCD photometry of stellar and non-stellar objects in the outer regions of the starburst galaxy M 82 in order to select globular clusters candidates. The CCD images were obtained with the 2m NAO-Rozhen telescope and cover a field of $\sim 15' \times 7'$. Combining theoretical predictions and observational data for typical magnitudes and colors of globular clusters, ~ 10 candidates for GC emerged on the CM diagrams. They form two distinctive groups probably due to age differences.

The next steps in our GCs populations study in M 82 are:

i) to complement the photometry with data from the Rozhen data archive (performing investigation for color dependence in the transformation equations) which will let us *ii*) to construct representative color-color diagrams. Thus the analysis of the globular cluster population will be more complete and accurate; *iii*) to perform cross-identification with objects from 2MASS catalog.

Acknowledgements

This research was partially supported by the grant F-1302/2003 with the National Science Foundation, Bulgaria.

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